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UNITED STATES SPACE SCIENCE PROGRAM

Report to COSPAR

Tenth Meeting
London, England
July 1967



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Submitted by SPACE SCIENCE BOARD



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NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1967

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United States
Space Science Program;
Report to COSPAR.

Foreword

The term space science, as used in the title of this report, refers to scientific work based on observations or measurements made in space, which is broadly interpreted to include the upper atmosphere, ionosphere and magnetosphere as well as the Moon, planets and interplanetary space. The vehicles used include artificial earth satellites, lunar landers and orbiters, planetary and other "deep" space probes, sounding rockets of varying size and capability, high altitude balloons and occasionally high altitude research aircraft. The term is not considered, in this context, to include scientific work conducted primarily for the purpose of providing background for the further development of space vehicle technology, although much work of this latter kind is being done in the United States.

The reporting period is the calendar year 1966, although frequent reference is made to the analytical results completed in 1966, based on observations made from vehicles launched during previous years. In a few instances, events are mentioned that occurred in early 1967, prior to the final preparation of this report (April 1967). Where appropriate, plans and preparation for future space science experiments have also been included.

The information contained in this document has been gathered from a large number of sources by the Space Science Board. We are indebted to many scientists and to many public and private institutions for their contributions and cooperation. Despite our desire for completeness, some important work may have been inadvertently omitted or inadequately covered. It is hoped that these annual summaries will prove useful as a means of indicating specifically and also of suggesting the nature and scope of space investigations carried out in the United States.

Richard W. Porter
Representative to COSPAR
U.S. National Academy of Sciences

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PART I

Organization of Space Research and Related Activities in The United States

Responsibility for the National Program

Primary responsibility for space research in the United States is assigned by law to the National Aeronautics and Space Administration. As space tools are developed by NASA into operational systems, or when a mission-oriented agency (public or private) can apply these powerful new tools to solution of its problems, space research and its applications diffuse throughout the government and spill over into the private sector.

Space research scientists of the United States are represented in COSPAR by the Space Science Board of the U.S. National Academy of Sciences and its Committee on International Relations. The Space Science Board is also responsible for SPACEWARN and the World Data Center A for Rockets and Satellites. The Academy maintains close liaison between the Space Science Board and its Geophysics Research Board, its Committee on International Programs for Atmospheric Sciences and Hydrology, and its committees and panels for other specialized activities, such as the International Years of the Quiet Sun and the World Magnetic Survey. The Space Science Board maintains close working relationships with NASA, the National Science Foundation, the scientific office of the Department of Defense, and other U.S. Government agencies.

In addition to organizations participating in previous years, space interests are now identified in the Department of Agriculture and the Department of Health, Education and Welfare, while the Ford Foundation expresses serious intent in entering the field from the private sector. In the case of Agriculture, crop diseases, pest control, land uses, rainfall, and the like can be studied on a continental scale from space vehicles in orbit. HEW, through its Public Health Service, is interested in possible back-contamination by samples and crews returned from extraterrestrial bodies. The Ford Foundation has identified the educational potential of communications satellites as an area which it would like to develop in the interests of all mankind.

Mention should also be made of the Communications Satellite Corporation (COMSAT). This government-regulated privately owned organization was established in 1963 and, as set forth in the Communications Satellite Act of 1962, is responsible for the development and operation of commercial satellite communication systems in the United States. COMSAT serves as the U.S. representative to the International Telecommunication Satellite Consortium

INTELSAT and, under an interim agreement, also acts as managing and operating agency for INTELSAT. It engages in a variety of space research activities appropriate to its primary objectives.

With the additions noted above, space research in the United States continues to be supported by those organizations shown in the chart at the beginning of the U.S. Report to COSPAR, May 1966. A revision of this diagram showing major participating agencies and their relations at the end of 1966 is shown in the following chart.

ABBREVIATIONS OF ORGANIZATIONS

ACIC	- Air Chart and Information Center (USAF)
AEC	- Atomic Energy Commission
AFCLR	- Air Force Cambridge Research Laboratories
AFOAR	- Air Force Office of Aerospace Research
AFOSR	- Air Force Office of Scientific Research
AFSC	- Air Force Systems Command
AGU	- American Geophysical Union
AIO	- Arecibo Ionospheric Observatory (USAF/Cornell U.)
AMS	- Army Map Service
ANL	- Argonne National Laboratory (AEC/U. Chicago)
APL	- Applied Physics Laboratory (Navy/JHU)
ARC	- Ames Research Center (NASA)
ARO	- Army Research Office
ARPA	- Advanced Research Projects Agency (DOD)
AUI	- Associated Universities, Inc.
AURA	- Association of Universities for Research in Astronomy
BNW	- Bureau of Naval Weapons
BRL	- Ballistic Research Laboratories (Army)
CIT	- California Institute of Technology
COMSAT	- Communications Satellite Corporation
CPR	- Committee on Polar Research (NAS-NRC)
DASA	- Defense Atomic Support Agency (DOD)
DSN	- Deep Space Network (NASA)
ERL	- Electronics Research Laboratory, Cambridge, Mass. (NASA)
ESSA	- Environmental Science Services Administration (Includes USWB, USG&GS, and ITSA)
ETR	- Eastern Test Range (NASA)
GISS	- Goddard Institute for Space Studies (NASA)
GRB	- Geophysics Research Board (NAS-NRC)
GSFC	- Goddard Space Flight Center (NASA)
HAO	- High Altitude Observatory (NCAR)
HCSR	- E. O. Hulburt Center for Space Research (NSF/ONR)
ITSA	- Institute of Telecommunications Science & Aeronomy (ESSA)
JHU	- Johns Hopkins University

JILA - Joint Industry for Laboratory Astrophysics (NBS/U. Colo.)
 JPL - Jet Propulsion Laboratory (NASA/CIT)
 KPNO - Kitt Peak National Observatory (NSF/AURA)
 LaRC - Langley Research Center (NASA)
 LASL - Los Alamos Scientific Laboratory (AEC/U. California)
 LPL - Lunar and Planetary Laboratory (U. Arizona)
 LRL - Lawrence Radiation Laboratory (AEC/U. California)
 MIT - Massachusetts Institute of Technology
 MSC - Manned Spacecraft Center (NASA)
 MSFC - Marshall Space Flight Center (NASA)
 NADC - Naval Air Development Center
 NAS-NRC - National Academy of Sciences - National Research Council
 NASA - National Aeronautics and Space Administration
 NBS - National Bureau of Standards
 NCAR - National Center for Atmospheric Research (NSF/UCAR)
 NESC - National Environmental Satellite Center (ESSA)
 NRAO - National Radio Astronomy Observatory (NSF/AUI)
 NRL - Naval Research Laboratory
 NSF - National Science Foundation
 NWL - Naval Weapons Laboratory
 OAR - Office of Aerospace Research (USAF)
 OIA - Office of International Affairs (NASA)
 ONR - Office of Naval Research
 OSR - Office of Scientific Research (USAF)
 RIAS - Research Institute for Advanced Studies (The Martin Company)
 SAO - Smithsonian Astrophysical Observatory
 SCAS - Southwest Center for Advanced Studies
 SEL - Stanford Electronics Laboratories
 SPO - Sacramento Peak Observatory
 SSB - Space Science Board (NAS-NRC)
 TRW - TRW Systems Group (formerly Space Technology Laboratories)
 UCAR - University Corporation for Atmospheric Research
 UCLA - University of California at Los Angeles
 USAECOM - U.S. Army Electronics Command
 USAERDL - U.S. Army Electronics Research and Development Laboratory

USAF - U.S. Air Force
USC&GS - U.S. Coast & Geodetic Survey (ESSA)
USGS - U.S. Geological Survey
USWB - U.S. Weather Bureau (ESSA)
WDC - World Data Center
WTR - Western Test Range (NASA)

International Activities

1. DATA EXCHANGE

In accordance with Section 2.2 of the COSPAR Guide and with the practice followed by the U.S. National Academy of Sciences since the IGY, the international scientific community was informed, through SPACEWARN communications and by announcement in the press, within a few hours of successful launch of scientific satellites, manned spacecraft, and satellite test vehicles of scientific interest. Up to date orbital elements for U.S. satellites have been distributed periodically via SPACEWARN in SATOR code.

Flight summaries of sounding rockets launched by U.S. experimenters during 1966 have been distributed by World Data Center A for Rockets and Satellites to WDC's B and C. Reports of experimental results of rocket and satellite launchings are regularly received by WDC-A from U.S. experimenters and distributed to WDC's B and C in the form of reprints of published research papers or as reports and data. Reports of satellite and space probe launchings in the condensed form adopted by COSPAR, and detailed reports describing the experiments and instruments for all U.S. scientific satellites and space probes launched during 1966 have been prepared and submitted to COSPAR and the World Data Centers. Monthly summaries of sounding-rocket launchings, listing the type of experiment and the name and address of the experimenters, were prepared on a regular basis and distributed to the scientific community by WDC-A on behalf of COSPAR.

In accordance with resolutions adopted by COSPAR at its meetings in Nice, February 1960, and in Washington, May 1962, WDC-A has continued to publish semi-annual catalogues of the rocket and satellite data it holds. The last biennial cumulative catalogue of these data, for the period 1 January 1964 to 31 December 1965, was prepared and submitted to COSPAR in May 1966. The next one will be submitted in early 1968. Meteorological data obtained by sounding rockets are now being collected and published by the WDC-A for Meteorology in monthly "Data Reports of Meteorological Rocket Network Firings." Reports have been issued for the months from January 1964 through July 1966.

2. INTERNATIONAL COOPERATIVE PROGRAMS AT NASA

During 1966 NASA continued to make progress in cooperative space activities which have involved scientists in some 70 countries. In addition, NASA sought to extend the scope and character of cooperation to comprehend still larger projects and deeper involvement with interested countries in space exploration. NASA's cooperative projects include both flight and ground-based projects and, closely related to them, a three-fold program of education and training in space sciences and engineering.

Flight Projects

(1) Cooperative satellite projects. In 1966, the Canadian satellites Alouette 1 (1962 Beta Alpha 1) and Alouette 2 (1965-98A) launched by NASA, continued to probe the ionosphere as the Sun passed its quiet period. The next three satellites in this series, designed to cover an entire solar-activity cycle, are scheduled for launching by NASA in 1967, 1968, and 1969. The first satellite launched in cooperation with France, FR-1 (1965-101A), completed its first year in space on December 6. Nearing launching readiness at year's end were the first ESRO (European Space Research Organization) spacecraft, the third British satellite, and Italy's San Marco 2. All three are scheduled for launching on NASA Scout vehicles early in 1967, the first two from the U.S. Western Test Range and the latter from an Italian platform positioned off the East African coast near the equator.

NASA and the French National Center for Space Studies (CNES) reached agreement on a new experimental project that is expected to demonstrate the scientific value and technical feasibility of collecting global weather data from constant-level instrumented balloons by means of an Earth-orbiting satellite (EOLE/FR-2). Agreement was also reached between NASA and the Federal Ministry for Scientific Research of the Federal Republic of Germany on a joint U.S.-German satellite project, an aeronomy-research spacecraft. NASA cooperative satellite projects, including a list of the scientific experiments, are summarized in Table 2-1.

(2) Coordinated satellite projects. Experimental two-way transmissions of satellite weather data over a special shared-cost facsimile link between Suitland, Maryland, and Moscow took place in September and October, while Soviet satellite data, including both cloud-cover photographs and nephelanalyses, were available. In the meantime, reciprocal exchange of conventional meteorological data continued over the link. NASA's coordinated satellite projects with the Soviet Union are summarized in Table 2-2.

(3) Foreign experiments on NASA satellites. In 1966, the total of foreign experiments selected for flight on NASA satellites reached 19. Thirteen additional proposals for experiments of this type were under consideration. Arrangements for foreign experiments on NASA satellites are summarized in Table 2-3.

(4) Cooperative sounding-rocket projects. In 1966, 124 sounding rockets were launched, bringing the cumulative total to 279.

Spain and Greece entered into agreements with NASA for cooperative sounding-rocket

TABLE 2-1.

COOPERATIVE SATELLITE PROJECTS (1)					
COUNTRY, NAME, LAUNCH SITE & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION	
CANADA					
● ALOUETTE I WESTERN TEST RANGE <u>SEP 29, 1962</u>	THOR-AGENA B NEAR POLAR, 80° CIRCULAR 1000 KM	DRTE	CANADIAN TELECOMMUNICATIONS ESTABLISHMENT (DRTE)	SOUND IONOSPHERE FROM ABOVE (TOPSIDE SOUNDERS) TO MEASURE HOUR-TO-HOUR ELECTRON DENSITIES OF IONOSPHERE. DETERMINE ELECTRON DENSITY AT HEIGHT OF SATELLITE MONITOR VLF NOISE IN RANGE OF 1 TO 10 KC/S	
			CANADIAN NATIONAL RESEARCH COUNCIL (NRC)	MEASURE PRIMARY COSMIC RAY PARTICLES OUTSIDE THE EARTH'S ATMOSPHERE	
● ALOUETTE II WESTERN TEST RANGE <u>NOV 29, 1965</u>	THOR-AGENA B NEAR POLAR, 80° APOGEE 3000 KM PERIGEE 500 KM	DRTE	DRTE AND NRC GOODARD SPACE FLIGHT CENTER (GSFC)	SAME CANADIAN EXPERIMENTS AS ALOUETTE I DETERMINE ELECTRON TEMPERATURE IN VICINITY OF ORBITING SPACECRAFT	
● 1515-1 (INTERNA- TIONAL SATELLITE FOR IONOSPHERE STUDIES) 1967	IMPROVED DELTA POLAR APOGEE 3500 KM PERIGEE 500 KM	DRTE	DRTE	SWEEP AND FIXED-FREQUENCY TOPSIDE SOUNDERS SUPPLEMENTED BY EIGHT ADDITIONAL EXPERIMENTS, FOUR CANADIAN AND FOUR U.S.	
● 1515-2 1969	IMPROVED DELTA NEAR 75° CIRCULAR 1700 KM	DRTE	DRTE	SWEEP AND FIXED FREQUENCY TOPSIDE SOUNDERS SUPPLEMENTED BY TEN ADDITIONAL EXPERIMENTS, SIX CANADIAN AND FOUR U.S.	
● 1515-3 1971	IMPROVED DELTA TO BE DETERMINED	DRTE	TO BE DETERMINED	TO BE DETERMINED.	

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COOPERATIVE SATELLITE PROJECTS					
COUNTRY, NAME, LAUNCH SITE & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION	
FRANCE					
● FR-1 WESTERN TEST RANGE DEC 6, 1965	SCOUT NEAR POLAR CIRCULAR 750 KM	NATIONAL CENTER FOR SPACE STUDIES (CNES)	NATIONAL CENTER FOR TELECOMMUNICATIONS STUDIES (CNET)	SIMULTANEOUSLY MEASURE THE ELECTRIC AND MAGNETIC COMPONENTS OF VERY LOW FREQUENCY (VLF) RADIO EMISSIONS, AND MEASURE ELECTRON DENSITIES	
● FR-2 (EOLE) WALLOPS ISLAND 1969	SCOUT INCLINATION 50° CIRCULAR 800 KM	NATIONAL CENTER FOR SPACE STUDIES (CNES)	SERVICE D'ASTRONOMIE, LA METEOROLOGIE NATIONALE, AND CNES	DETERMINE FEASIBILITY OF A SATELLITE-BALLOON SYSTEM TO GATHER METEOROLOGICAL DATA ON A GLOBAL SCALE. TESTS WILL INCLUDE SATELLITE INTERROGATION OF INSTRUMENTED BALLOONS DRIFTING AT CONSTANT LEVELS IN THE SOUTHERN HEMISPHERE.	
FEDERAL REPUBLIC OF GERMANY					
● PROJECT 625A-1 LATE 1968	SCOUT NEAR POLAR APOGEE 2500 KM PERIGEE 250 KM	FEDERAL MINISTRY FOR SCIENTIFIC RESEARCH	MAX-PLANCK INSTITUTE FOR PHYSICS AND ASTROPHYSICS UNIVERSITY OF KIEL MAX-PLANCK INSTITUTE FOR AERONOMY	MEASURE ENERGY SPECTRUM OF PROTONS IN 1 TO 100 MEV REGION MEASURE OMNIDIRECTIONAL FLUX OF PROTONS (6 TO 170 MEV) AND ELECTRONS (0.3 TO 3 MEV). MEASURE ENERGY SPECTRUM OF PROTONS IN 100 KEV TO 2 MEV REGION MEASURE ELECTRONS ABOVE 40 KEV ENERGY THRESHOLD MEASURE ENERGY SPECTRUM OF PROTONS IN 135 TO 250 MEV REGION	

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TABLE 2-1. (continued)

COOPERATIVE SATELLITE PROJECTS (A)					
COUNTRY, NAME, LAUNCH SITE & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION	
ITALY					
PROJECT "SAN MARCO"		ITALIAN SPACE COMMISSION*	SCHOOL OF AEROSPACE ENGINEERING, UNIVERSITY OF ROME UNIVERSITY OF FLORENCE	DETERMINE LOCAL DENSITY OF UPPER ATMOSPHERE (PHASE II) AND LOCAL DENSITY OF EQUATORIAL UPPER ATMOS- PHERE (PHASE III) BY MEASURING THE INSTANTANEOUS AERODYNAMIC DRAG ON THE RESPECTIVE SATELLITES. IONOSPHERIC PROPAGATION STUDIES (FARADAY ROTATION TECHNIQUE) USING BEACON (PHASE II AND PHASE III).	
● PHASE I WALLOPS ISLAND AUGUST, 1963	SHOTPUT SUB- ORBITAL LAUNCH				
● PHASE II WALLOPS ISLAND DEC 15, 1964	SCOUT INCLINATION 40° NEAR CIRCULAR 200-400 KM				
● PHASE III TOWABLE PLAT- FORM IN INDIAN OCEAN EQUATO- RIAL WATERS EARLY 1967	SCOUT INCLINATION 2.5° APOGEE 800 KM PERIGEE 214 KM				

*ITALIAN SPACE COMMISSION ALSO RESPONSIBLE FOR PHASE II AND III LAUNCHINGS.

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COOPERATIVE SATELLITE PROJECTS (A)					
COUNTRY, NAME, LAUNCH SITE & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION	
UNITED KINGDOM					
● ARIEL I EASTERN TEST RANGE <u>APR 26, 1962</u>	DELTA INCLINATION 56° APOGEE 1200 KM PERIGEE 400 KM	GSFC	IMPERIAL COLLEGE, LONDON	MEASURE SPECTRUM OF PRIMARY COSMIC RAY ENERGIES AND ITS VARIATIONS, WITH CERENKOV DETECTOR.	
			UNIVERSITY OF BIRMINGHAM	MEASURE LOCAL ELECTRON DENSITY WITH RF IMPEDANCE PROBE	
			UNIVERSITY COLLEGE, LONDON	MEASURE ELECTRON TEMPERATURE AND DENSITY WITH LANGMUIR PROBE.	
				MEASURE ION MASS COMPOSITION AND TEMPERATURE WITH MASS SPECTROMETER.	
				MEASURE ENERGY SPECTRUM OF SOLAR HARD X-RAYS.	
				MEASURE SOLAR ULTRAVIOLET EMISSIONS (LYMAN-ALPHA).	
● ARIEL II WALLOPS ISLAND <u>MAR 27, 1964</u>	SCOUT INCLINATION 51° APOGEE 1200 KM PERIGEE 290 KM	GSFC	METEOROLOGICAL OFFICE, U.S. AIR MINISTRY	MEASURE ATMOSPHERIC OZONE WITH FILTERED PHOTOCELLS AND SPECTROMETER.	
			MULARD RADIO ASTRONOMY OBSERVATORY, UNIVERSITY OF CAMBRIDGE	MEASURE GALACTIC RADIO NOISE.	
			NUFFIELD RADIO ASTRONOMY LABORA- TORIES, JODRELL BANK	MEASURE MICROMETEOROID FLUX BY OPTICAL DETECTION OF HOLES FORMED IN A THIN METALLIC FILM	

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TABLE 2-1. (continued)

COOPERATIVE SATELLITE PROJECTS (5)

COUNTRY, NAME, LAUNCH SITE & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION
<u>UNITED KINGDOM (CONTINUED)</u>				
● UK-3 WESTERN TEST RANGE EARLY 1967	SCOUT INCLINATION 80° CIRCULAR 550 KM	ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH	METEOROLOGICAL OFFICE, U. K. AIR MINISTRY UNIVERSITY OF MANCHESTER UNIVERSITY OF SHEFFIELD RADIO AND SPACE RESEARCH STATION, SLOUGH UNIVERSITY OF BIRMINGHAM	MEASURE VERTICAL DISTRIBUTION OF MOLECULAR OXYGEN IN EARTH'S ATMOSPHERE MEASURE LARGE-SCALE NOISE SOURCES IN GALAXY. MEASURE INTENSITY OF VLF RADIATION. MEASURE INTENSITY AND GEOGRAPHICAL DISTRIBUTION OF SOURCES OF NATURAL TERRESTRIAL NOISE. MEASURE ELECTRON DENSITY AND TEMPERATURE.

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COOPERATIVE SATELLITE PROJECTS (6)

COUNTRY, NAME, LAUNCH SITE & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION
<u>EUROPEAN SPACE RESEARCH ORGANIZATION (ESRO)</u>				
● ESRO I WESTERN TEST RANGE LATE 1967	SCOUT NEAR POLAR APOGEE 1500 KM PERIGEE 275 KM	ESRO	DENMARK NORWAY SWEDEN U.K. U.K. U.K.	TECHNICAL UNIVERSITY UNIVERSITY OF OSLO KIRUNA GEOPHYSICAL OBSERVATORY QUEEN'S UNIVERSITY, BELFAST RADIO RESEARCH STATION, SLOUGH UNIVERSITY COLLEGE, LONDON (TWO EXPERIMENTS)
● ESRO II WESTERN TEST RANGE EARLY 1967	SCOUT NEAR POLAR APOGEE 1500 KM PERIGEE 350 KM	ESRO	FRANCE NETHERLANDS U.K. U.K. U.K.	SACLAY CENTER FOR NUCLEAR PHYSICS STERRE WACHT, UTRECHT IMPERIAL COLLEGE, LONDON (THREE EXPERIMENTS) UNIVERSITY OF LEEDS UNIVERSITY OF LEICESTER AND UNIVERSITY COLLEGE, LONDON
● NEOS - A	(PURCHASED DELTA LAUNCHING.)			

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TABLE 2-2.

COORDINATED SATELLITE PROJECTS					
COUNTRY, NAME, LAUNCH SITE & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION	
<u>USSR</u>					
● METEOROLOGICAL SATELLITE PROJECT	TIROS/NIMBUS	NASA	GSFC AND U.S. WEATHER BUREAU	(1) EXCHANGE OF DATA GATHERED BY NATIONAL EXPERIMENTAL METEOROLOGICAL SATELLITES OVER WASHINGTON-MOSCOW COMMUNICATIONS LINK.	
1965 --	- - -	ACADEMY OF SCIENCES OF USSR	- - -	(2) COORDINATED LAUNCHINGS OF NATIONAL EXPERIMENTAL METEOROLOGICAL SATELLITES.	
● SATELLITE TELECOMMUNI- CATIONS	THOR-AGENA B	NASA	GSFC AND UNIVERSITY OF MANCHESTER, U.K.	COOPERATIVE COMMUNICATIONS EXPERIMENTS BY MEANS OF U.S. PASSIVE SATELLITE, ECHO II.	
<u>FEB., 1964</u>	INCLINATION 82° APOGEE 1200 KM PERIGEE 980 KM	ACADEMY OF SCIENCES OF USSR			
● MAPPING OF THE GEOMAG- NETIC FIELD	THRUST-AUGMENTED THOR-AGENA	NASA	GSFC	(1) LAUNCHING BY EACH COUNTRY OF AN EARTH SATELLITE EQUIPPED WITH ABSOLUTE MAGNETO- METERS.	
1965 --	INCLINATION 84° APOGEE 925 KM PERIGEE 280 KM			(2) EXCHANGE OF PROCESSED SATELLITE MAGNETIC- MEASUREMENT DATA FROM NATIONAL PROGRAMS.	
	- - -	ACADEMY OF SCIENCES OF USSR	ACADEMY OF SCIENCES OF USSR		

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TABLE 2-3.

FOREIGN EXPERIMENTS ON NASA SATELLITES (1)					
COUNTRY, NAME & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION	
FRANCE FIVE EXPERIMENTS:					
● ORBITING GEOPHYSICAL OBSERVATORIES (OGO-B, OGO-D) <u>OCT. 14, 1965, 1967</u>	THRUST-AUGMENTED THOR-AGENA INCLINATION 84° APOGEE 975 KM PERIGEE 260 KM	GOODARD SPACE FLIGHT CENTER (GSFC)	SERVICE D'AERONOMIE, NATIONAL SCIENTIFIC RESEARCH CENTER (CNRS) GSFC (CO-EXPERIMENTER)	MEASURE AIRGLOW AT 4300 Å, 5577 Å, 2914 Å, AND IN THE NEAR ULTRAVIOLET REGION WITH PHOTOMETER.	
● ORBITING SOLAR OBSERVATORY (OSO-F) 1968	DELTA INCLINATION 33° CIRCULAR 550 KM	GSFC	CNRS	MEASURE SELF-REVERSAL OF THE SOLAR LYMAN-ALPHA SPECTROGRAPHIC LINE.	
● ORBITING GEOPHYSICAL OBSERVATORY (OGO-E) 1967	ATLAS-AGENA INCLINATION 31° APOGEE 148,000 KM PERIGEE 275 KM	GSFC	UNIVERSITY OF PARIS	DETERMINE NUMBER, DENSITY AND TEMPERATURE OF HYDROGEN AND DENSITY OF DEUTERIUM IN GEOCORONA WITH HYDROGEN-DEUTERIUM CELL.	
● ORBITING GEOPHYSICAL OBSERVATORY (OGO-F) 1968	THRUST-AUGMENTED THOR-AGENA NEAR POLAR APOGEE 930 KM PERIGEE 235 KM	GSFC	CNRS	MEASURE ALTITUDE DISTRIBUTION OF NITROGEN AND OXYGEN IN AURORA AND DEDUCE TEMPERATURE OF NEUTRAL COMPONENTS OF THE ATMOSPHERE.	

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TABLE 2-3. (continued)

FOREIGN EXPERIMENTS ON NASA SATELLITES (2)				
COUNTRY, NAME & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION
<u>ITALY</u>				
● ORBITING SOLAR OBSERVATORY (OSO-C) 1969	DELTA INCLINATION 33° CIRCULAR 350 KM	GSFC	UNIVERSITY OF BOLOGNA	SOLAR X-RAY MONITORING AND GAMMA ASTRONOMY IN THE ENERGY RANGE 20-200 KEV.
<u>NETHERLANDS</u>				
● ORBITING GEOPHYSICAL OBSERVATORY (OGO-E) 1967	ATLAS-AGENA INCLINATION 31° APOGEE 140,000 KM PERIGEE 275 KM	GSFC	DELFT TECHNICAL INSTITUTE	SIX-COUNTER TELESCOPE TO MEASURE ABSOLUTE FLUX AND ENERGY SPECTRUM OF COSMIC RAY ELECTRONS
<u>UNITED KINGDOM</u>				
ELEVEN EXPERIMENTS				
● EXPLORER XX (U.S. FIXED-FREQUENCY TOP-SIDE SOUNDER) AUG 25, 1964	SCOUT NEAR POLAR APOGEE 1375 KM PERIGEE 925 KM	GSFC	UNIVERSITY COLLEGE, LONDON	MEASURE ION MASS COMPOSITION AND TEMPERATURE WITH ION MASS SPECTROMETER (SIMILAR EXPERIMENT ON ARIEL 1.)

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FOREIGN EXPERIMENTS ON NASA SATELLITES (3)				
COUNTRY, NAME & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION
<u>UNITED KINGDOM</u> (CONTINUED)				
● ORBITING ASTROPHYSICAL OBSERVATORY (OAO-C) 1970	ATLAS-AGENA INCLINATION 32° CIRCULAR 780 KM	GSFC	UNIVERSITY OF LEICESTER AND UNIVERSITY COLLEGE, LONDON	STUDY THE X-RAY EMISSION OF STARS AND NEBULAE AND OBTAIN INFORMATION ON THE INTERSTELLAR ABSORPTION OF H ₂ AND THE HEAVIER ELEMENTS.
● ORBITING SOLAR OBSERVATORY (OSO-D) 1967	DELTA INCLINATION 33° CIRCULAR 350 KM	GSFC	UNIVERSITY OF LEICESTER AND UNIVERSITY COLLEGE, LONDON	(1) MEASURE DISTRIBUTION OF TOTAL SOLAR X-RAY EMISSION OVER A WIDE BAND. (2) STUDY SOLAR H ₂ II RESONANCE EMISSION (304 Å).
● ORBITING SOLAR OBSERVATORY (OSO-F) 1968	DELTA INCLINATION 33° CIRCULAR 350 KM	GSFC	UNIVERSITY OF LEICESTER AND UNIVERSITY COLLEGE, LONDON	MEASURE SOLAR X-RAY FLUX WITH SPECTROHELIOGRAPH.
● EXPLORER XXX (DIRECT MEASUREMENT EXPLORER) NOV 29, 1965	THOR-AGENA B INCLINATION 60° APOGEE 3000 KM PERIGEE 500 KM (RECOVERABLE WITH ALOUETTE II)	GSFC	UNIVERSITY COLLEGE, LONDON	(1) MEASURE ION MASS COMPOSITION AND TEMPERATURE WITH SPHERICAL ION MASS SPECTROMETER (SIMILAR EXPERIMENT ON ARIEL 1.) (2) MEASURE ELECTRON TEMPERATURE WITH PLANAR ELECTRON TEMPERATURE PROBE.

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TABLE 2-3. (continued)

FOREIGN EXPERIMENTS ON NASA SATELLITES					(4)
COUNTRY, NAME & DATE	VEHICLE & ORBIT	SPACECRAFT RESPONSIBILITY	EXPERIMENTERS	EXPERIMENT DESCRIPTION	
UNITED KINGDOM (CONTINUED)					
● ● ORBITING GEOPHYSICAL OBSERVATORY (OGO-E) 1967	ATLAS-AGENA INCLINATION 31° APOGEE 148,000 KM PERIGEE 275 KM	GSFC	UNIVERSITY COLLEGE, LONDON UNIVERSITY OF SOUTHAMPTON	(1) SPHERICAL PROBE TO MEASURE ELECTRON DENSITY AND TEMPERATURE. (2) SPARK CHAMBER TO MEASURE DIRECTION OF INCIDENCE OF UNCHARGED PRIMARY COSMIC RAYS.	
● ORBITING SOLAR OBSERVATORY (OSO-G) 1969	DELTA INCLINATION 33° CIRCULAR 550 KM	GSFC	UNIVERSITY COLLEGE, LONDON	STUDY OF SOLAR H _ε I AND H _ε II RESONANCE RADIATION BY MEANS OF A TWIN-LINE MONOCHROMETER.	
● NIMBUS D 1970	THOR-AGENA INCLINATION 80° NEAR CIRCULAR 1250 KM	GSFC	READING UNIVERSITY OXFORD UNIVERSITY	SELECTIVE CHOPPER RADIOMETRIC TEMPERATURE PROBE.	

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programs, bringing to 19 the total of countries having such arrangements with the United States. In addition, new sounding-rocket projects were negotiated with Argentina, Brazil, Germany, Japan, and the Netherlands.

With respect to Spain, Memoranda of Understanding signed in January 1966 provide for a cooperative program in meteorological sounding rockets utilizing the acoustic grenade experiment and the smaller Arcas- and boosted-Dart-class sounding rockets. The launch site is at Huelva, near Cadiz. The Spanish technicians completed their training at NASA's Wallops Station in August 1966, and launches from the Huelva site were initiated in October.

Cooperative programs of testing and cross-calibrating meteorological sounding rockets, payloads, and ground equipment developed by other nations along with similar U.S. equipment are being worked out in recognition of COSPAR recommendations. In this manner, internationally obtained data become directly comparable and of significantly increased validity and utility.

The Experimental Inter-American Meteorological Rocket Network (EXAMETNET) was established in 1965 by agreement with Argentina and Brazil as a cooperative program to extend sounding-rocket measurements on an experimental basis into Latin America. Beginning January 12, 1966, from Natal, Brazil, and April 27 from Chical, Argentina, boosted-Dart-type sounding rockets were launched. As of December 31, 1966, a total of 53 meteorological rockets had been launched from these stations. Plans for increasing the number of launch sites and the scope of the program were discussed at the EXAMETNET meeting held at Chical in September 1966. By such an expanded program, and by utilizing data from other existing sites, it would be possible to study the structure and circulation of the atmosphere in both the Northern and Southern Hemispheres and the interrelation of the atmospheric behavior in both hemispheres.

NASA cooperative sounding-rocket projects are summarized in Table 2-4. (See also Chapter 6 for discussions of the Global Meteorological Rocket Network.)

Ground-Based Projects

The 1966 launchings of the Applications Technology Satellite ATS-1 (1966-110A), and of PAGEOS, a passive reflector satellite (1966-56A), made possible an extension of cooperation in which ground-based observations were coordinated in support of satellite programs in communications, meteorology, and geodesy. NASA's ground-based cooperative projects are summarized in Table 2-5.

Other Cooperative Projects

In the first arrangement of its kind, a Memorandum of Understanding was concluded during 1966 between the European Space Research Organization and NASA which provides for the purchase of launchings from the United States for ESRO spacecraft.

French and Israeli scientists participated as guest observers in connection with Maurer camera photography from Gemini 9. NASA and German scientists joined in a high-altitude balloon sounding using a high-resolution solar spectro-telescope designed to gain new knowledge of fine structure of the solar atmosphere. Four foreign experimenters joined

TABLE 2-4.

COOPERATIVE SOUNDING ROCKET PROJECTS (1)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>ARGENTINA</u>			
ARGENTINE NATIONAL COMMISSION FOR SPACE RESEARCH (CNR)	2 NIKE-CAJUN ABOVE 90 KM	CAMICAL, ARGENTINA DEC, 1964	NATIONAL UNIVERSITY OF TUCUMAN: MEASURE D AND E REGION ELECTRON DENSITY AND TEMPERATURE, ION DENSITY, AND ULTRA-VIOLET RADIATION.
	3 NIKE-APACHE 90-140 KM	CAMICAL EARLY 1967	NATIONAL UNIVERSITY OF TUCUMAN: INVESTIGATE PHYSICAL PROCESSES PRODUCING SPORADIC E
	16 BOOSTED DART AND ARCAS	CAMICAL APR-DEC, 1966	CNR PROJECT CONSTITUTES ONE ELEMENT OF INTER-AMERICAN EXPERIMENTAL, METEOROLOGICAL SOUNDING ROCKET NETWORK (EXAMETNET).
	30 BOOSTED DART AND ARCAS 30-60 KM	1967	
	12 ARCAS 60 KM	TARTAGAL, ARGENTINA NOV. 1966	ATMOSPHERIC SCIENCES LABORATORY, CNR: OBSERVE CHANGES IN WIND, TEMPERATURE, AND OZONE IN THE UPPER ATMOSPHERE ASSOCIATED WITH THE TOTAL SOLAR ECLIPSE OF NOVEMBER 12, 1966
	3 ORION 85 KM	WALLOPS ISLAND NOV. 1966	ARGENTINE RESEARCH AGENCIES OBTAIN DATA ON VEHICLE FLIGHT PERFORMANCE CHARACTERISTICS FOR ARGENTINE-BUILT SOUNDING ROCKETS
<u>AUSTRALIA</u>			
DEPARTMENT OF SUPPLY	4 SKYLARK 200 KM	WOODMIRA, AUSTRALIA SEP-NOV., 1961	NASA-GODDARD SPACE FLIGHT CENTER: MEASURE STELLAR AND NEBULAR ULTRAVIOLET RADIATION IN SOUTHERN SKIES. COMBART WITH NORTHERN HEMISPHERE DATA.
COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION (CSIRO)	2 AROBEE 150 A ABOVE 120 KM	WALLOPS ISLAND APR-MAY, 1963	CSIRO: MEASURE VLF RADIO NOISE IN THE IONOSPHERE

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COOPERATIVE SOUNDING ROCKET PROJECTS (2)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>BRAZIL</u>			
BRAZILIAN NATIONAL COMMISSION FOR SPACE RESEARCH (CNAE)	1 NIKE-APACHE 80 KM REGION	WALLOPS ISLAND AUG., 1965	CNAE-NASA-GODDARD SPACE FLIGHT CENTER: EVALUATE COSMIC RAY EFFECTS ON THE LOWER D REGION OF THE IONOSPHERE
	2 NIKE-APACHE 80 KM REGION	NATAL, BRAZIL DEC., 1965	
	17 BOOSTED DART AND ARCAS	NATAL JAN-DEC 1966	CNAE PROJECT CONSTITUTES ONE ELEMENT OF INTER-AMERICAN EXPERIMENTAL METEOROLOGICAL SOUNDING ROCKET NETWORK (EXAMETNET).
	30 BOOSTED DART AND ARCAS 30-60 KM	1967	
	9 NIKE-CAJUN 40-100 KM	NATAL MAY-OCT 1966 1967	CNAE-NASA, GODDARD SPACE FLIGHT CENTER: MEASURE WIND, TEMPERATURE, PRESSURE AND DENSITY USING "GRENADE" TECHNIQUE.
	12 NIKE-APACHE NIKE-TOMAHAWK NIKE-HYDAC NIKE-JAVELIN 180 KM-700 KM	CASSINO, BRAZIL NOV., 1966	VARIOUS U.S. AND BRAZILIAN EXPERIMENTERS STUDY THE EFFECTS OF THE SOLAR ECLIPSE OF NOVEMBER 12, 1966 ON THE EARTH'S ATMOSPHERE. INVESTIGATE SOLAR X-RAY SOURCE FUNCTIONS.
	1 AROBEE 150 205 KM	NATAL DEC., 1966	CATHOLIC UNIVERSITY: IDENTIFY NEW X-RAY SOURCES IN THE SOUTHERN HEMISPHERE.

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TABLE 2-4. (continued)

COOPERATIVE SOUNDING ROCKET PROJECTS (3)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>CANADA</u>			
CANADIAN NATIONAL RESEARCH COUNCIL	APPROX. 20 NASA-SPONSORED LAUNCHINGS PER YEAR	CHURCHILL RESEARCH RANGE, CANADA JAN. 1, 1966 TO JUN. 30, 1970	VARIOUS CANADIAN AND U.S. EXPERIMENTERS USE THE RANGE FOR LAUNCHING SOUNDING ROCKETS IN AUSTRAL ZONE TO STUDY ATMOSPHERIC AND IONOSPHERIC PHENOMENA.
	0 BLACK BRANT 100 KM	WALLOPS ISLAND JUN/DEC, 1962	CANADIAN RESEARCH AGENCIES DETERMINE VEHICLE FLIGHT PERFORMANCE CHARACTERISTICS AND OBTAIN ENGINEERING DATA ON EFFECTIVENESS OF INSTRUMENTATION. COSMIC RAY SENSOR AND MAGNETOMETER INCLUDED. (CHURCHILL RESEARCH RANGE FACILITIES INOPERATIVE DURING THIS PERIOD DUE TO FIRE DAMAGE.)
<u>FRANCE</u>			
FRENCH NATIONAL CENTER FOR SPACE STUDIES (CNES)	2 AEROBEE 150 2 AEROBEE 150 ABOVE 280 KM	WALLOPS ISLAND OCT., 1963 SEP., 1965	NATIONAL CENTER FOR TELECOMMUNICATIONS STUDIES (CNIT) STUDY IRREGULARITIES IN THE IONOSPHERE THROUGH SIMULTANEOUS MEASUREMENTS OF VLF FIELD STRENGTH AND LOCAL ELECTRON DENSITY.
	2 FRENCH DRAGON 2 FRENCH CENTAURE	HAMMAGUER, ALGERIA APR., 1964	CNES-NASA GODDARD SPACE FLIGHT CENTER SIMULTANEOUSLY MEASURE CHARGED PARTICLE AND NEUTRAL GAS TEMPERATURES IN THE IONOSPHERE.
	1 AEROBEE 150 A APPROX. 280 KM	WHITE SANDS, N. M. NOV., 1965	CNES- ONE OF SEVERAL EXPERIMENTERS PROVIDING SPECIAL SAMPLING SURFACES TO COLLECT AND ANALYZE EXTRATERRESTRIAL DUST PARTICLES AS PART OF PROJECT LUSTER

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COOPERATIVE SOUNDING ROCKET PROJECTS (4)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>FEDERAL REPUBLIC OF GERMANY</u>			
MINISTRY FOR SCIENTIFIC RESEARCH	1 AEROBEE 150 A 1 AEROBEE 150 A APPROX. 280 KM	WHITE SANDS NOV., 1964 NOV., 1965	MAX-PLANCK INSTITUTE FOR NUCLEAR PHYSICS ONE OF SEVERAL EXPERIMENTERS PROVIDING SPECIAL SAMPLING SURFACES TO COLLECT AND ANALYZE EXTRATERRESTRIAL DUST PARTICLES AS PART OF PROJECT LUSTER.
	1 NIKE-APACHE	WALLOPS ISLAND AUG., 1966	IONOSPHERIC INSTITUTE OF BREISACH VARIABLE FREQUENCY IMPEDANCE PROBE TO MEASURE ELECTRON DENSITY
MINISTRY FOR SCIENTIFIC RESEARCH	1 JAVELIN APPROX. 950 KM	WALLOPS ISLAND SEP., 1966	MAX-PLANCK INSTITUTE FOR PHYSICS AND ASTROPHYSICS OBSERVATIONS OF ARTIFICIAL ION CLOUDS TO INVESTIGATE THE PHYSICS OF COMETS, THE INTERPLANETARY MEDIUM, AND THE EARTH'S MAGNETOSPHERE.
	1 NIKE-TOMAHAWK APPROX. 300 KM	WALLOPS ISLAND SEP., 1966	
MINISTRY FOR SCIENTIFIC RESEARCH	1 NIKE-APACHE APPROX. 250 KM	CHURCHILL RESEARCH RANGE, CANADA NOV., 1966	MAX-PLANCK INSTITUTE FOR AERONOMY, IONOSPHERIC INSTITUTE OF BREISACH, AND GERMAN EXPERIMENTAL CENTER FOR AVIATION AND SPACE FLIGHT: TO FLIGHT TEST INSTRUMENTATION FOR THE GERMAN RESEARCH SATELLITE AND INVESTIGATE UV EMISSION INTENSITIES AND PROTON AND ELECTRON FLUX DURING AN AURORAL EVENT.
MINISTRY FOR SCIENTIFIC RESEARCH	1 JAVELIN APPROX. 1000 KM	NATAL, BRAZIL EARLY 1967	MAX-PLANCK INSTITUTE FOR AERONOMY, UNIVERSITY OF KIEL, MAX-PLANCK INSTITUTE FOR EXTRATERRESTRIAL PHYSICS AND TECHNICAL UNIVERSITY, BRUNSWICK: FLIGHT TEST INSTRUMENTATION FOR THE GERMAN RESEARCH SATELLITE AND INVESTIGATE PROTON AND ELECTRON ENERGY SPECTRA, PROTON FLUX, AND SOLAR AND GALACTIC ALPHA PARTICLES.

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TABLE 2-4. (continued)

COOPERATIVE SOUNDING ROCKET PROJECTS ⁽¹⁾			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>GREECE</u>			
GREEK NATIONAL COMMITTEE FOR SPACE RESEARCH	7 BOOSTED ARCAS APPROX. 95 KM	NASA SHIP OFF KORONI, GREECE MAY, 1966	GSFC INVESTIGATE RELATIONSHIP BETWEEN THE VARIATION IN IONIZATION BELOW 90 KM AND CHANGES IN SOLAR UV AND X-RAY FLUX DURING TOTAL SOLAR ECLIPSE.
<u>INDIA</u>			
INDIAN NATIONAL COMMITTEE FOR SPACE RESEARCH (INCOSPAR) OF THE DEPARTMENT OF ATOMIC ENERGY	4 NIKE-APACHE 150 KM	THUMBIA, INDIA JAN, 1964	UNIVERSITY OF NEW HAMPSHIRE INVESTIGATE THE EQUATORIAL ELECTROJET AT THE GEOMAGNETIC EQUATOR BY MEANS OF MAGNETOMETER INSTRUMENTATION.
	7 NIKE-APACHE 150 KM	THUMBIA NOV 1963 JAN-NOV, 1964	PHYSICAL RESEARCH LABORATORY, AHMEDABAD: (1) MEASURE UPPER ATMOSPHERE WINDS BY GROUND PHOTOGRAPHY OF ILLUMINATED SODIUM VAPOUR RELEASED FROM ROCKET.
	2 NIKE-APACHE 5 NIKE-APACHE 150 KM	THUMBIA MAR, 1966 EARLY 1967	(2) MEASURE UPPER ATMOSPHERE WINDS BY GROUND PHOTOGRAPHY OF ILLUMINATED CHEMICALS RELEASED FROM ROCKET.
	1 NIKE-APACHE 2 NIKE-APACHE 150 KM	THUMBIA JUL, 1966 EARLY 1967	(3) INVESTIGATE RELATIONSHIP BETWEEN WIND SHEARS AND SPO-RADIC E BY COMBINING MEASUREMENTS UNDER (2) ABOVE, WITH ELECTRON DENSITY MEASUREMENT.
			PHYSICAL RESEARCH LABORATORY AHMEDABAD: INVESTIGATE THE EQUATORIAL ELECTROJET AT GEOMAGNETIC EQUATOR BY MEANS OF MAGNETOMETER INSTRUMENTATION.

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COOPERATIVE SOUNDING ROCKET PROJECTS ⁽¹⁾			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>INDIA (CONTINUED)</u>			
	2 NIKE-APACHE 150 KM	THUMBIA 1967	NATIONAL PHYSICAL LABORATORY, NEW DELHI: MEASURE ELECTRON AND ION DENSITIES AND LYMAN- α AND X-RAY FLUX.
	1 NIKE-APACHE 150 KM	THUMBIA EARLY 1967	PHYSICAL RESEARCH LABORATORY, AHMEDABAD: INVESTIGATE SOURCES OF X-RAY EMISSIONS IN THE SOUTHERN SKY.
	30 BOOSTED DART	THUMBIA 1964-1966	INCOSPAR METEOROLOGICAL ROCKET SOUNDINGS (CHAFF) SUPPLEMENTING THE INDIAN OCEAN EXPEDITION.
<u>ISRAEL</u>			
NATIONAL COMMITTEE FOR SPACE RESEARCH	1 AEROBEE 150 A APPROX. 280 KM	WHITE SANDS NOV, 1965	UNIVERSITY OF TEL AVIV: ONE OF SEVERAL EXPERIMENTERS PROVIDING SPECIAL SAMPLING SURFACES TO COLLECT AND ANALYZE EXTRATERRESTRIAL DUST PARTICLES AS PART OF PROJECT LUSTER.
<u>ITALY</u>			
ITALIAN SPACE COMMISSION	8 NIKE-CAJUN AND NIKE-ASP 80-200 KM	SARDINIA JAN/APR, 1961 DEC, 1962	ITALIAN SPACE COMMISSION: MEASURE UPPER ATMOSPHERE WINDS BY GROUND PHOTOGRAPHY OF ILLUMINATED SODIUM VAPOUR RELEASED FROM ROCKET.
<u>JAPAN</u>			
JAPANESE RADIO RESEARCH LABORATORIES	3 NIKE-CAJUN 100-130 KM	WALLOPS ISLAND APR/MAY, 1962	JAPANESE RADIO RESEARCH LABORATORIES AND NASA GODDARD SPACE FLIGHT CENTER: COMBINE JAPANESE SWEPT FREQUENCY RESONANCE PROBE WITH GSFC LANGMUIR PROBE FOR ELECTRON DENSITY AND TEMPERATURE DETERMINATION.
	2 AEROBEE 150 A ABOVE 130 KM	WALLOPS ISLAND SEP, 1963	

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TABLE 2-4. (continued)

COOPERATIVE SOUNDING ROCKET PROJECTS (7)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>JAPAN (CONTINUED)</u>			
	1 JAVELIN ABOVE 200 KM	WALLOPS ISLAND OCT, 1964	
JAPANESE SCIENCE AND TECHNOLOGY AGENCY AND JAPANESE METEOROLOGICAL AGENCY	10 MT-135 10 ARCAS OR BOOSTED DART APPROX. 60 KM	WALLOPS ISLAND 1967	JAPANESE SCIENCE AND TECHNOLOGY AGENCY, JAPANESE METEOROLOGICAL AGENCY AND NASA WALLOPS STATION: OBTAIN COMPARISON DATA ON OPERATIONAL CHARACTERISTICS OF THE ROCKETS; GAIN ADDITIONAL INFORMATION ON DIURNAL WIND AND TEMPERATURE CYCLES.
<u>NETHERLANDS</u>			
NETHERLANDS ORGANIZATION FOR ADVANCEMENT OF PURE RESEARCH	4 NIKE-APACHE UP TO 120 KM	CORONIE, SURINAM SEP, 1965	UNIVERSITY OF UTRECHT, ASTRONOMICAL OBSERVATORY: INVESTIGATION OF UPPER ATMOSPHERE EQUATORIAL WINDS BY GROUND-BASED PHOTOGRAPHY OF ILLUMINATED SODIUM VAPOR RELEASED FROM PAYLOADS WITH SIMULTANEOUS MEASUREMENTS OF IONOSPHERIC DRIFT (MIRA-METHOD).
LABORATORY FOR SPACE RESEARCH (LRO)	1 AEROSIE 150 A APPROX. 200 KM	WHITE SANDS, N. M. EARLY 1967	LRO: OBSERVATION OF THE SPATIAL DISTRIBUTION OF SOLAR X-RAY SOURCES BY MEANS OF ZONE PLATE TELESCOPES AND A FINE ALTITUDE CONTROL SYSTEM.
<u>NEW ZEALAND</u>			
NEW ZEALAND NATIONAL SPACE RESEARCH COMMITTEE	1 ARCAS 2 ARCAS	BIRDLING'S FLAT, N. Z. MAY, 1963 SEP DEC, 1964	UNIVERSITY OF CANTERBURY, NEW ZEALAND: MEASURE WIND DRIFT AND TURBULENT DIFFUSION IN THE D REGION OF THE IONOSPHERE BY ROCKET BORNE RADIO PROPAGATION MEASUREMENTS AND BY GROUND-BASED PHOTOGRAPHY OF ILLUMINATED AEROSOL RELEASED FROM ROCKET.

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COOPERATIVE SOUNDING ROCKET PROJECTS (8)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>NEW ZEALAND (CONTINUED)</u>			
	1 BOOSTED ARCAS APPROX. 95 KM	KARAKARA PENINSULA, N. Z. MAY, 1965	RANGE AND EXPERIMENT VALIDATION.
	6 BOOSTED ARCAS APPROX. 95 KM	KARAKARA PENINSULA MAY, 1965	(1) UNIVERSITY OF CANTERBURY: DIFFERENTIAL ABSORPTION WITH GROUND-BASED SOUNDERS. (2) NASA GSFC: ELECTRON DENSITY BY FARADAY ROTATION TECHNIQUE.
<u>NORWAY/DENMARK</u>			
NORWEGIAN COMMITTEE FOR SPACE RESEARCH JOINTLY WITH ROYAL TECHNICAL UNIVERSITY OF DENMARK	1 NIKE-CAJUN 1 NIKE-APACHE 2 NIKE-CAJUN ABOVE 90 KM	WALLOPS ISLAND DEC, 1961 JUN, 1962 MAR/APR, 1963	NASA GSFC WITH NORWEGIAN PARTICIPATION (WALLOPS LAUNCHINGS), NORWEGIAN DRE AND ROYAL TECHNICAL UNIVERSITY OF DENMARK (ANDØYA LAUNCHINGS) MEASURE D AND E REGION ELECTRON AND ION DENSITY AND ELECTRON COLLISION FREQUENCY BY RADIO ABSORPTION EXPERIMENT, FARADAY ROTATION EXPERIMENT AND RF IMPEDANCE AND CONDUCTIVITY PROBES. LYMAN-ALPHA MONITOR (WALLOPS) AND ENERGETIC PARTICLES EXPERIMENT (ANDØYA) ALSO INCLUDED.
	3 NIKE-CAJUN 1 NIKE-APACHE 3 NIKE-APACHE ABOVE 90 KM	ANDØYA, NORWAY AUG/DEC, 1967 SEP, 1963 MAR, 1964	
	4 NIKE-APACHE 1 NIKE-APACHE 2 NIKE-APACHE ABOVE 90 KM	ANDØYA MAR, NOV, 1965 JUNE 1966 EARLY 1967	

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TABLE 2-4. (continued)

COOPERATIVE SOUNDING ROCKET PROJECTS (19)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
NORWAY-DENMARK (CONTINUED)			
NORWEGIAN COMMITTEE FOR SPACE RESEARCH	2 BOOSTED ARCAS UP TO 80 KM	ANDØYA NOV. DEC. 1965	NASA GSFC AND NORWEGIAN DRE. SUPPORT FOR GROUND-BASED CROSS-MODULATION STUDIES OF THE IONOSPHERE USING FARADAY ROTATION TECHNIQUE.
	1 NIKE-APACHE 50-85 KM	ANDØYA MAR. 1966	NASA GSFC AND NORWEGIAN DRE. STUDY THE IONIC COM- POSITION OF THE D REGION WITH AN ION-SPECTROMETER PAYLOAD.
	1 NIKE-APACHE 50-85	WALLOPS ISLAND LATE 1967	
	4 SIDEWINDER-ARCAS APPROX. 100 KM	ANDØYA MID - 1967	NASA GSFC AND NORWEGIAN DRE. LAUNCH EXPERIMENTS INTO PCA EVENT TO STUDY RELATIONSHIPS BETWEEN SUDDEN INCREASE IN RADIO WAVE ABSORPTION AND FLUX OF LOW ENERGY INCOMING PARTICLES.
PAKISTAN			
PAKISTAN SPACE AND UPPER ATMOSPHERE RESEARCH COMMITTEE (SUPARCO)	2 NIKE-CAJUN 1 NIKE-CAJUN 80-125 KM	SONMIANI BEACH PAKISTAN JUN. 1962 MAY, 1963	SUPARCO. MEASURE UPPER ATMOSPHERE WINDS BY GROUND-BASED PHOTOGRAPHY OF ILLUMINATED SODIUM VAPOR RELEASED FROM PAYLOAD.
	3 NIKE-APACHE 2 NIKE-APACHE 125-200 KM	SONMIANI BEACH APR. NOV. DEC. 1964 FEB. 1966	
	30 BOOSTED DART 2 BOOSTED DART	SONMIANI BEACH 1964-1965 1967	SUPARCO. METEOROLOGICAL ROCKET SOUNDINGS (CHAFF) SUPPLE- MENTING THE INTERNATIONAL INDIAN OCEAN EXPEDITION.

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COOPERATIVE SOUNDING ROCKET PROJECTS (19)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
PAKISTAN (CONTINUED)			
SUPARCO JOINTLY WITH BRITISH NATIONAL COMMITTEE ON SPACE RESEARCH (BNCSR)	2 NIKE-CAJUN 80-125 KM	SONMIANI BEACH APR. 1963	SUPARCO AND BNCSR. MEASURE WIND, TEMPERATURE, PRESSURE, AND DENSITY USING "GRENADE" TECHNIQUE.
	3 NIKE-APACHE 1 NIKE-APACHE 125-200 KM	SONMIANI BEACH MAR. APR. 1966 1967	
SPAIN			
SPANISH NATIONAL SPACE COMMISSION (CONAE)	3 BOOSTED DART 11 BOOSTED DART 60 KM	HUELVA, SPAIN OCT. NOV. 1966 1967	NATIONAL AEROSPACE INSTITUTE (INTA). MEASURE WIND AND TEMPERATURE USING CHAFF OR INSTRUMENTED SONDES.
	4 NIKE-CAJUN 80-125 KM	HUELVA 1967	INTA. MEASURE WIND, TEMPERATURE, PRESSURE, AND DENSITY USING "GRENADE" TECHNIQUE.
SWEDEN			
SWEDISH SPACE RESEARCH COMMITTEE	1 ARCAS 80 KM	JÖNKÖP, SWEDEN AUG. 1961	UNIVERSITY OF STOCKHOLM.
	4 NIKE-CAJUN UP TO 130 KM	KIRUNA, SWEDEN AUG. 1967	(1) MEASURE WINDS DURING OCCURRENCE OF NOCTILUCENT CLOUDS BY OPTICAL TRACKING OF SMOKE TRAIL CREATED BY RELEASE OF AEROSOL POWDER FROM ROCKET. (2) DIRECT SAMPLING OF NOCTILUCENT CLOUDS WITH RECOVER- ABLE CONTAINER. ALSO THERMIST PARTICLES EXPERIMENT (KIRUNA GEOPHYSICAL OBSERVATORY).

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TABLE 2-4. (continued)

COOPERATIVE SOUNDING ROCKET PROJECTS (11)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTER AND PROJECT DESCRIPTION
<u>SWEDEN (CONTINUED)</u>			
	4 NIKE-CAJUN UP TO 100 KM	KRONOGARD <u>AUG. 1963</u>	(3) MEASURE UPPER ATMOSPHERE TEMPERATURE, WIND, PRESSURE, AND DENSITY DURING OCCURRENCE OF NOCTILUCENT CLOUDS BY MEANS OF ROCKETS INSTRUMENTED WITH EXPLOSIVE CHARGES AND ASSOCIATED ELECTRONICS.
	4 NIKE-APACHE UP TO 120 KM	KRONOGARD <u>AUG. 1964</u>	(4) DIRECT SAMPLING OF NOCTILUCENT CLOUDS WITH RECOVERABLE CONTAINER
	4 NIKE-APACHE UP TO 120 KM	KRONOGARD <u>AUG. 1964</u>	(5) MEASURE UPPER ATMOSPHERE TEMPERATURE, WIND, PRESSURE, AND DENSITY DURING OCCURRENCE OF NOCTILUCENT CLOUDS BY MEANS OF ROCKETS INSTRUMENTED WITH EXPLOSIVE CHARGES AND ASSOCIATED ELECTRONICS
	1 AEROSOL 150 A APPROX. 280 KM	WHITE SANDS <u>NOV. 1963</u>	(6) ONE OF SEVERAL EXPERIMENTERS PROVIDING SPECIAL SAMPLING SURFACES TO COLLECT AND ANALYZE EXTRATERRESTRIAL DUST PARTICLES AS PART OF PROJECT LUSTER. UPPSALA IONOSPHERIC OBSERVATORY
	3 BOOSTED ARCAS APPROX. 95 KM	WHITE SANDS <u>OCT-DEC. 1963</u>	(11) MEASURE ION AND ELECTRON DENSITIES IN D REGION OF IONOSPHERE.

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COOPERATIVE SOUNDING ROCKET PROJECTS (12)			
COUNTRY AND COOPERATING AGENCY	NUMBER, TYPE OF ROCKET AND ALTITUDE	LAUNCH SITE AND DATE	EXPERIMENTERS AND PROJECT DESCRIPTION
<u>SWEDEN (CONTINUED)</u>			
	1 BOOSTED ARCAS APPROX. 95 KM	WALLOPS ISLAND <u>MAR. 1964</u>	UPPSALA IONOSPHERIC OBSERVATORY (CONTINUED) (2) MEASURE UPPER ATMOSPHERE WINDS BY GROUND-BASED PHOTOGRAPHY OF SODIUM-LITHIUM RELEASES FROM PAYLOAD
	2 BOOSTED ARCAS APPROX. 95 KM	ANDØYA <u>MAR. 1965</u>	(3) MEASURE ION AND ELECTRON DENSITIES IN D REGION OF IONOSPHERE FROM THE AURORAL ZONE.
	1 NIKE-APACHE UP TO 120 KM	ANDØYA <u>MAR. 1965</u>	(4) MEASURE WINDS AND SODIUM EMISSIONS IN AURORAE
	1 NIKE-APACHE UP TO 120 KM	ANDØYA <u>MAR. 1965</u>	(5) MEASURE AURORAL PHENOMENA BY OBSERVING THE EFFECTS OF AN ARTIFICIAL SHOCK WAVE CREATED BY A HIGH-ENERGY EXPLOSIVE CHARGE.
<u>UNITED KINGDOM</u>			
BRITISH NATIONAL COMMITTEE FOR SPACE RESEARCH	2 NIKE-APACHE UP TO 120 KM	WALLOPS ISLAND <u>JUL/NOV. 1964</u>	UNIVERSITY OF BIRMINGHAM, UNIVERSITY OF ILLINOIS AND GEOPHYSICS CORPORATION OF AMERICA: COMBINE BRITISH RADIO FREQUENCY CAPACITANCE PROBE WITH LANGMUIR PROBE, RADIO PROPAGATION EXPERIMENT, AND ENERGIC PARTICLE SENSORS TO CHECK RELIABILITY OF IONOSPHERIC MEASUREMENT TECHNIQUES.
	1 AEROSOL 150 A APPROX. 280 KM	WHITE SANDS <u>NOV. 1963</u>	BIRKBECK COLLEGE: ONE OF SEVERAL EXPERIMENTERS PROVIDING SPECIAL SAMPLING SURFACES TO COLLECT AND ANALYZE EXTRATERRESTRIAL DUST PARTICLES AS PART OF PROJECT LUSTER.

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TABLE 2-5.

COOPERATIVE GROUND-BASED PROJECTS (1)					INTERNATIONAL PARTICIPATION
PROJECT					
METEOROLOGICAL SATELLITES:					
THE FIRST METEOROLOGICAL SATELLITE WAS LAUNCHED BY NASA IN APRIL, 1960 AND SINCE THEN TIROS, ESSA AND Nimbus SATELLITES HAVE BEEN OBTAINING TELEVISION PICTURES OF CLOUD FORMATIONS AND PATTERNS AND MEASURING THE ABSORPTION AND REFLECTION OF INFRARED SOLAR RADIATION BY THE EARTH AND ITS ATMOSPHERE.					NASA AND THE ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION (ESSA) HAVE PROVIDED AN OPPORTUNITY FOR DIRECT FOREIGN PARTICIPATION IN WEATHER SATELLITE OPERATIONS. IN 1961 FOREIGN WEATHER SERVICES WERE INVITED TO CONDUCT GROUND OBSERVATIONS SYNCHRONIZED WITH SATELLITE PHOTOGRAPHY AND EXCHANGE THE RESULTS. FORTY COUNTRIES TOOK PART IN THIS PROGRAM UNTIL ITS TERMINATION IN MID-1965. BEGINNING WITH TIROS III IN 1963 AND CONTINUING WITH THE ESSA AND Nimbus SATELLITES, THE AUTOMATIC PICTURE TRANSMISSION SUBSYSTEM PROVIDES AN OPPORTUNITY FOR DIRECT READ-OUT OF LOCAL CLOUD COVER PICTURES USING RELATIVELY SIMPLE GROUND EQUIPMENT. API SETS ARE NOW OPERATING IN OVER THIRTY COUNTRIES.
COMMUNICATIONS SATELLITES:					
PROJECTS RELAY, TELSTAR, AND SYNCOM HAVE BEEN DESIGNED TO DETERMINE THE FEASIBILITY OF TRANSOCEANIC COMMUNICATIONS VIA ACTIVE REPEATER SATELLITES. THESE SATELLITES PICK UP AND AMPLIFY SIGNALS RECEIVED FROM GROUND STATIONS AND THEN RETRANSMIT THEM BACK TO EARTH.					FIFTEEN COUNTRIES HAVE PROVIDED GROUND STATIONS FOR COOPERATIVE PROGRAMS WITH THE UNITED STATES IN THE TESTING OF U.S. EXPERIMENTAL COMMUNICATIONS SATELLITES SINCE 1962 (ENGLAND, FRANCE, ITALY, AND BRAZIL (FIRST OPERATIONAL 1962); GERMANY AND JAPAN (1962); DENMARK, NORWAY AND SWEDEN OPERATING A JOINT RECEIVING FACILITY, AND SPAIN (1964); AND CANADA (1966). NEARLY ALL STATIONS HAVE CONDUCTED EXPERIMENTS INVOLVING TRANSMISSION OF TELEPHONE, TELEGRAPH, AND HIGH SPEED DATA AS WELL AS INTERCONTINENTAL TELEVISION EXPERIMENTS.
NAME	LAUNCH DATE	NOMINAL ORBIT			
		INCLINATION	APOGEE	PERIGEE	
*TELSTAR I	7-10-62	49°	5800 KM	950 KM	
*RELAY I	12-13-62	47°	7425 KM	1300 KM	
TELSTAR II	5-07-63	43°	10555 KM	925 KM	
SYNCOM II	7-18-63	32.5°	35900 KM	35791 KM	
RELAY II	1-21-64	46.5°	7401 KM	2129 KM	
SYNCOM III	8-19-64	0°	35790 KM	35790 KM	
*INACTIVE					THE FIRST LIVE TELEPHONE CONVERSATION VIA SATELLITE BETWEEN HEADS OF GOVERNMENT TOOK PLACE IN AUGUST 1963 WHEN PRESIDENT KENNEDY SPOKE WITH THE PRIME MINISTER OF NIGERIA, WHICH HOSTED THE USNS KINGSFORD AS THE AFRICAN TERMINAL FOR SYNCOM II IN LAGOS HARBOR. SYNCOM III IN OCTOBER, 1964 CARRIED LIVE TELEVISION COVERAGE OF THE OLYMPIC GAMES IN JAPAN.

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COOPERATIVE GROUND-BASED PROJECTS (2)					INTERNATIONAL PARTICIPATION
PROJECT					
APPLICATIONS TECHNOLOGY SATELLITES:					
THE ATS PROJECT OBJECTIVE IS TO INVESTIGATE SPACE TECHNOLOGY WHICH IS COMMON TO A NUMBER OF SATELLITE APPLICATIONS. SPIN AND GRAVITY GRADIENT STABILIZATION TECHNIQUES, AS WELL AS SHF, VHF COMMUNICATION, METEOROLOGICAL DATA, MICRO-THRUSTERS, AND VARIOUS SCIENCE EXPERIMENTS ARE INCLUDED.					THE ELEVEN NATIONS MENTIONED UNDER "COMMUNICATIONS SATELLITES" ABOVE, PLUS INDIA (WHICH IS CURRENTLY ESTABLISHING A GROUND STATION TO WORK WITH EXPERIMENTAL COMMUNICATIONS SATELLITES), HAVE BEEN INVITED TO PARTICIPATE IN THE COMMUNICATIONS EXPERIMENTS ON ATS. DUE TO VISIBILITY LIMITATIONS IMPOSED BY ATS-I LOCATION (STATIONARY OVER CENTRAL PACIFIC) JAPAN CURRENTLY IS ONLY PARTICIPANT AUSTRALIA, THROUGH GANTAS, IS PARTICIPATING IN THE VHF AERONAUTICAL COMMUNICATIONS EXPERIMENT USING THE ATS-I VHF TRANSDUCER.
NAME	LAUNCH DATE	NOMINAL ORBIT			
		INCLINATION	APOGEE	PERIGEE	
ATS-I	12-4-66	0.3°	35,785 KM	35,783 KM	APT GROUND STATIONS IN JAPAN, CANADA, AUSTRALIA, NEW ZEALAND, TAIPEI AND THE FIJI ISLANDS, MAY PARTICIPATE IN THE JOINT NASA-ESSA WEFAX (METEOROLOGICAL FACSIMILE) EXPERIMENT USING THE ATS-I VHF TRANSDUCER.
GEOLOGIC SATELLITES:					
GEO S I (EXPLORER XXXX), AN ACTIVE SATELLITE CONTAINING INSTRUMENTATION FOR OPTICAL AND ELECTRONIC OBSERVATIONS, AND PAGEOS, A PASSIVE REFLECTOR SATELLITE LAUNCHED FOR LARGE-SCALE OPTICAL OBSERVATIONS, WERE DESIGNED FOR A WORLD-WIDE GEOLOGIC PROGRAM TO DETERMINE MORE ACCURATELY THE SIZE AND SHAPE OF THE EARTH.					FIFTEEN NON-U.S. STATIONS IN EIGHT COUNTRIES ARE OBSERVING OR HAVE OBSERVED THE GEO S AND PAGEOS SATELLITES PHOTOGRAPHICALLY IN AN EFFORT TO IMPROVE GEOLOGIC DATA ACCURACIES. FRANCE ALSO PARTICIPATED IN THE GEO S LASER TRACKING EXPERIMENT.
NAME	LAUNCH DATE	NOMINAL ORBIT			
GEO S I	11-4-65		2300 - 1100 KM		
PAGEOS	6-22-66		CIRCULAR 4160 KM		
LASER OBSERVATIONS:					
UPPER ATMOSPHERE PARTICLE STUDIES					THE SWEDISH SPACE RESEARCH COMMITTEE AND NASA ARRANGED FOR A MOBILE PULSED LASER RADAR, LOCATED IN SWEDEN, TO BE USED BEGINNING IN 1967 TO DETERMINE THE HEIGHT, DISTRIBUTION AND SCATTERING PROPERTIES OF COSMIC DUST AND AEROSOL PARTICLES DURING THE PRESENCE AND ABSENCE OF NOCTILUCENT CLOUDS.

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TABLE 2-5. (continued)

COOPERATIVE GROUND-BASED PROJECTS (3)

PROJECT

INTERNATIONAL PARTICIPATION

IONOSPHERIC SATELLITES:

A. TOPSIDE SOUNDER SATELLITES (ALOUETTES I AND II AND EXPLORER XX)

THE ALOUETTE SATELLITES USE A SWEEP FREQUENCY SOUNDER SYSTEM AND EXPLORER XX USED A FIXED FREQUENCY SYSTEM TO STUDY THE AMOUNT OF, AND VARIATION IN, IONOSPHERIC ELECTRON DENSITY.

NAME	LAUNCH DATE	NOMINAL ORBIT
ALOUETTE I	<u>9-27-62</u>	NEAR POLAR CIRCULAR 1000 KM
EXPLORER <u>XX</u>	<u>8-25-64</u>	NEAR POLAR 1375 - 725 KM
ALOUETTE II	<u>11-29-62</u>	NEAR POLAR 3000 - 500 KM

B. BEACON EXPLORER AND LASER TRACKING SATELLITES (EXPLORERS XXXX AND XXXX)

EXPLORERS XXX AND XXXX PROVIDE THE MEANS FOR SYNOPSIS STUDY OF THE IONOSPHERE BY GROUND-BASED OBSERVATIONS OF RADIO SIGNALS TRANSMITTED FROM THE SATELLITE AND FOR EXPERIMENTS IN SATELLITE TRACKING BY LASER BEAMS DIRECTED TO EXPLORERS XXXX AND XXXX AND RETURNED TO GROUND-BASED RECEIVERS BY SPECIAL REFLECTORS.

NAME	LAUNCH DATE	NOMINAL ORBIT
EXPLORER <u>XXX</u>	<u>10-19-64</u>	NEAR POLAR CIRCULAR 1200 KM
EXPLORER <u>XXXX</u>	<u>4-20-65</u>	INCLINATION 41° CIRCULAR 1000 KM

NUMEROUS U. S. AND CANADIAN STATIONS, AND TWENTY-THREE STATIONS IN FOURTEEN OTHER COUNTRIES HAVE TAKEN OR ARE TAKING GROUND SOUNDINGS COORDINATED WITH SATELLITE SOUNDING WHICH PERMIT COMPARISON OF TOP AND BOTTOM-SIDE IONOSPHERIC PROFILES.

THE RADIO AND SPACE RESEARCH STATION OF THE UNITED KINGDOM SCIENCE RESEARCH COUNCIL IS STAFFING AND OPERATING THREE TELEMETRY STATIONS FOR THE ACQUISITION OF DATA FROM TOPSIDE SOUNDER SATELLITES. IN 1966, FRANCE, JAPAN AND NORWAY BEGAN TO OPERATE SIMILAR STATIONS.

SIXTY-THREE GROUND STATIONS IN THIRTY-ONE COUNTRIES PLUS ANTI-ARCTICA AND HONG KONG, ARE CARRYING OUR FARADAY ROTATION, SCINTILLATION, AND DOPPLER DIFFERENTIAL EXPERIMENTS TO MEASURE INTEGRATED ELECTRON DENSITY IN A VERTICAL PLANE BETWEEN THE SATELLITE AND A GROUND STATION BELOW, AND VARIATIONS IN ELECTRON DENSITY AS A FUNCTION OF LATITUDE SEASON, AND DIURNAL TIME. IN ADDITION TO THE ABOVE, FRANCE PARTICIPATED IN THE LASER TRACKING EXPERIMENT.

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U.S. scientists in observing the November 12 solar eclipse from a jet transport aircraft. These and other projects are summarized in Table 2-6.

Education and Training

(1) Training in connection with NASA cooperative projects. Training is an integral part of virtually every NASA cooperative project. The extent of training in any given program depends on the needs of the cooperating nation, its responsibilities in the joint project, and the scientific and technical character of the project itself. Thus, in one of its cooperative satellite projects, NASA provides training in satellite engineering, techniques for launching the satellite into orbit, procedures for tracking and acquisition of data from the satellite, and reduction and analysis of the data. In cooperative sounding-rocket projects, training may be provided in the fabrication of scientific payloads, in the procedures for rocket launching, in tracking and data acquisition, and in data reduction. This training is carried out at NASA centers such as the sounding-rocket range at Wallops Island, Virginia, or the Goddard Space Flight Center, near Washington, where foreign scientists and engineers work side by side with their NASA counterparts in actual operations connected with the joint projects. NASA assumes the cost of the training while the cooperating national space organizations provide for the costs of travel to and from the United States and for the salaries and subsistence of their personnel during the training period.

During 1966, 22 scientists, engineers, and technicians from 4 countries and ESRO received NASA training in connection with agreed cooperative programs. The distribution was:

Argentina	2	France	3
Brazil	7	Spain	8
ESRO		2	

(2) NASA Resident Research Associateships. Open to postdoctoral and senior postdoctoral investigators, these fellowships are intended to provide investigators of unusual ability and promise with an opportunity for research in space science and technology at NASA centers. The program is administered for NASA by the National Academy of Sciences - National Research Council. Stipend is \$11,000 a year.

Participating Centers

Ames Research Center	Moffett Field, Calif.
Goddard Space Flight Center	Greenbelt, Md.
Goddard Institute for Space Studies	New York, N.Y.
Electronics Research Center	Cambridge, Mass.
Jet Propulsion Laboratory	Pasadena, Calif.
Langley Research Center	Hampton, Va.
Manned Spacecraft Center	Houston, Tex.
Marshall Space Flight Center	Huntsville, Ala.

TABLE 2-6.

OTHER COOPERATIVE PROJECTS (1)			
PROJECT		INTERNATIONAL PARTICIPATION	
FOREIGN SPACECRAFT LAUNCHED BY NASA ON A REIMBURSABLE BASIS		NASA AND THE EUROPEAN SPACE RESEARCH ORGANIZATION (ESRO) HAVE AGREED THAT NASA WILL PROVIDE LAUNCHES FOR ESRO SCIENTIFIC SATELLITES ON A REIMBURSABLE BASIS. ESRO PROVIDES THE SPACECRAFT AND FUNDS THE IDENTIFIABLE DIRECT COSTS FOR THE LAUNCH VEHICLE, RANGE AND LAUNCHING FACILITIES AND OTHER SUPPORT, INCLUDING INITIAL TRACKING AND TELEMETRY RECEPTION. MEOS, THE FIRST SPACECRAFT TO BE LAUNCHED UNDER THE ARRANGEMENT, IS AN INTERPLANETARY RESEARCH SATELLITE DUE TO BE LAUNCHED IN LATE 1968 BY A NASA THOR-DELTA LAUNCH VEHICLE INTO A HIGHLY ELLIPTICAL ORBIT WITH AN APOGEE OF 200,000 KM.	
HIGHLY ECCENTRIC ORBIT SATELLITE (MEOS-A)			
GUEST OBSERVERS:		COUNTRY	EXPERIMENTERS
MAURER CAMERA PHOTOGRAPHY		FRANCE	NATIONAL SCIENTIFIC RESEARCH CENTER (CNRS)
GEMINI XII	NOV 11, 1966		
APOLLO 204	1967		
MAURER CAMERA PHOTOGRAPHY		ISRAEL	TEL AVIV UNIVERSITY
GEMINI XII	NOV 11, 1966		
			STUDY DAYTIME WIND VELOCITY VECTORS IN HIGH ATMOSPHERE BY IMAGING DEFORMATION OF THE VERTICAL SODIUM CLOUD. CLOUD PRODUCED BY FRENCH SOUNDING ROCKET LAUNCHED FROM HAMMAGUE, ALGERIA.
			PARTICIPATED AS CO-INVESTIGATOR WITH THE DUDLEY OBSERVATORY (US) IN STUDY OF DUST IN EARTH'S UPPER ATMOSPHERE BY ULTRAVIOLET IMAGING.

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OTHER COOPERATIVE PROJECTS (2)	
PROJECT	INTERNATIONAL PARTICIPATION
COOPERATIVE BALLOON SOUNDINGS:	
BALLOON SPECTROTELESCOPE	NASA AND THE FRAUNHOFER INSTITUTE OF FREIBURG, GERMANY ARE CONDUCTING THREE HIGH ALTITUDE BALLOON SOUNDINGS USING A HIGH RESOLUTION SOLAR SPECTROTELESCOPE DESIGNED TO GAIN NEW KNOWLEDGE OF FINE STRUCTURE ELEMENTS OF THE SOLAR ATMOSPHERE. NASA-PROVIDED MYLAR SCRIM BALLOONS CARRY THE INSTRUMENTS TO AN ALTITUDE OF ABOUT 80,000 FT. THE FIRST FLIGHT WAS CONDUCTED IN NOV. 1966, AND THE FINAL FLIGHTS ARE SCHEDULED FOR 1967. THE U.S. NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR) IS COOPERATING BY PROVIDING LAUNCHING SERVICES FROM THE BALLOON FLIGHT STATION, FALGOUT, TEXAS.
AIRBORNE SOLAR ECLIPSE OBSERVATIONS:	
SOLAR ECLIPSE FLIGHTS ON NASA COMNAVIR 990 DURING ECLIPSES OF MAY, 1963 AND NOV., 1966	EXPERIMENTERS FROM BELGIUM, ITALY, NETHERLANDS, AND SWITZERLAND JOINED U.S. SCIENTISTS IN STUDYING THE STRUCTURE AND COMPOSITION OF THE SOLAR ATMOSPHERE, SEARCHING FOR FAINT COMETS IN THE VICINITY OF THE SUN, AND CONDUCTING TEMPERATURE DISTRIBUTION STUDIES. FOREIGN AIRBORNE INSTRUMENTS WERE ACCOMMODATED ALONG WITH U.S. EXPERIMENTS IN THE AIRCRAFT, WHICH FLEW ALONG THE PATHS OF THE TOTAL ECLIPSES.

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TABLE 2-6. (continued)

OTHER COOPERATIVE PROJECTS (3)	INTERNATIONAL PARTICIPATION
<u>REVIEW OF SPACE BIOLOGY AND MEDICINE:</u> PREPARATION AND PUBLICATION OF NASA ACADEMY OF SCIENCES OF <u>USSR</u> JOINT REVIEW OF SPACE BIOLOGY AND MEDICINE.	A JOINT US/USSR EDITORIAL BOARD WILL COLLECT MATERIAL FROM BOTH SIDES IN AGREED SUBJECT AREAS, ASSIGN AUTHORS, AND ARRANGE FOR SCIENTIFIC AND EDITORIAL REVIEW. PUBLICATION OF THE FINAL VOLUMES IS SCHEDULED FOR 1968
<u>SCIENTIFIC AND TECHNICAL INFORMATION EXCHANGE</u> EXCHANGE OF SCIENTIFIC AND TECHNICAL INFORMATION THROUGH DOCUMENTS, MICROFICHE, AND COMPUTER SEARCH MATERIALS.	UNDER A LETTER AGREEMENT OF MAY, 1964, AMPLIFIED IN JUNE, 1965, NASA PROVIDES SCIENTIFIC AND TECHNICAL INFORMATION TO THE <u>ESRO/ILDO</u> DOCUMENT SERVICE WHICH, IN RETURN, FURNISHES INFORMATION COLLECTED FROM ITS MEMBER STATES. COMPATIBILITY OF FACILITIES MAKES POSSIBLE EXCHANGE OF MICROFICHE AND COMPUTER TAPES. UNDER INFORMAL ARRANGEMENTS, NASA MAINTAINS A PROGRAM OF DOCUMENT EXCHANGE WITH <u>27</u> INSTITUTIONS LOCATED IN <u>FOURTY-TWO</u> COUNTRIES.

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Status, Calendar Year 1966
(119 associates from 29 countries)

Argentina	1	Italy	3
Australia	4	Japan	11
Austria	1	Republic of Korea	4
Brazil	1	The Netherlands	1
Canada	2	New Zealand	1
Chile	1	Norway	2
Republic of China	4	Pakistan	1
Denmark	1	Republic of South Africa	4
France	7	Spain	1
Federal Republic of Germany	13	Sweden	1
Greece	2	Switzerland	1
India	26	United Arab Republic	2
Iran	1	United Kingdom	13
Ireland	1	Venezuela	1
Israel	8		

(3) NASA International University Fellowships in Space Science. Training in this program is at graduate and postdoctoral levels. Its purpose is to assist other nations in efforts to develop scientific space programs. The National Academy of Sciences - National Research Council administers the program for NASA. Funding is shared by U.S. (tuition, fees, research costs and travel in U.S.) and by the foreign sponsor (subsistence and overseas travel). Duration of fellowships is for one year, with possibility of renewal for a second year.

Cooperating Universities (27) and the scientific and technical fields in which fellowships are available are as follows:

University of Alabama

Applied mathematics; Biology; Chemistry; Engineering (aerospace, chemical, civil, electrical, engineering mechanics, industrial, mechanical, metallurgical, nuclear); Space Research (electromagnetics, gas dynamics, plasma technology, re-entry hypersonics, space communications).

University of Arizona

Astronomy, including lunar and planetary; Chemistry; Engineering (aerospace, chemical, civil, electrical, mechanical, nuclear); Engineering Mechanics; Mathematics; Metallurgy; Meteorology; Physics.

California Institute of Technology

Biological, Chemical, Geological, Mathematical, and Physical Sciences; Engineering.

University of California, Berkeley

Astronomy; Astrophysics; Atmospheric and Space Sciences; Biology; Chemistry; Engineering (aeronautical, chemical, electrical, heat-power systems, mechanical, mineral technology, nuclear, sanitary, structural); Exobiology; Genetics; Geology; Geophysics; Mathematics; Molecular Biology; Nutritional Sciences; Physics (atomic, medical, nuclear, plasma, solid state); Physiology; Satellite Theory; Statistics; Stellar Atmospheres and Structures.

University of California, Los Angeles

Astronomy; Astrophysics; Biology (environmental, radio, and systems); Bionics; Data Processing; Engineering (cyrogenic systems, heat-to-electricity conversion, special materials); Geochemistry; Geophysics; Meteorology; Physics (cosmic-ray, planetary); Space Chemistry.

University of Chicago

Astronomy; Astrophysics; Chemistry; Cosmic Rays; Geochemistry; Geophysics; Mathematics; Physics.

University of Cincinnati

Celestial Mechanics; Experimental Psychology; Heat and Mass Transfer; High Speed Gas Dynamics; Materials Science; Solid State Physics; Space Medicine and Biology; Structures and Structural Dynamics.

University of Colorado

Aerodynamics; Controlled Theory and Space Mechanics; Dynamic Meteorology; The Ionosphere; Physics (low energy atomic, planetary and interplanetary, plasma, solar, stellar atmospheres, upper atmosphere); Planetary and Solar Radio Astronomy; Space Perception.

Columbia University

Astrophysics (galaxies, interstellar medium, nucleosynthesis, radio astronomy, stellar structure); Engineering (communications and radar systems, controls and guidance, flight structures, gas dynamics, materials, plasma physics); Planetary Physics (general circulation of the atmosphere, magnetosphere and interplanetary plasma, origin of the solar system, physics of the upper atmosphere, planetary bodies and their atmospheres, radiative and convective transfer).

Cornell University

Aerodynamics; Applied Mathematics (as related to optimization of orbits and to information and control theory of space vehicles); Astrophysics; Cosmology; Gas Dynamics; Kinetic Theory; Magnetohydrodynamics; Physics (including lunar, planetary, plasma, space); Radio Astronomy; Stellar Structure.

Graduate Research Center of the Southwest, Dallas, Texas

Research Projects Only. Atmospheric Structure; Cosmic Radiation; Geochemistry; Geochronology; Geomagnetism; Ionospheric Physics; Molecular Biology; Petrology; Planetary Atmospheres; Plasma Physics; Reaction Kinetics; Relativity; Seismology.

Harvard University

Astronomy; Biology; Chemistry; Engineering; Geophysics; Mathematics; Physics.

University of Iowa

Aurora and Airglow; Cosmic Rays; Experimental Work with Rockets, Satellites, and Deep Space Probes; Geomagnetically Trapped Radiation; Geomagnetism; Particles in Interplanetary Space; Physics (magnetosphere, plasma, solar); VLF Radio Waves; Planetary Magnetism.

University of Maryland

Astronomy; Astrophysics; Cosmic Rays; General Relativity; Physics (atmospheric, plasma, space); Radio Astronomy.

Massachusetts Institute of Technology

Engineering (including space vehicle instrumentation); Industrial Management; Life Sciences (including nutrition); Mathematical Sciences; Physical Sciences; Social Sciences.

University of Michigan

Aeronomy; Astronomy; Astrophysics; Biological and Health Sciences; Chemistry; Cosmic Rays; Engineering (aeronautical, astronautical, chemical, electrical, information and control, materials, mechanical,

metallurgical, nuclear); Geology; Magnetohydrodynamics; Mathematics; Meteorology; Oceanography; Physics (including plasma); Psychology; Radio Astronomy.

University of Minnesota

Aeronautical Engineering; Aerospace Systems; Astrophysics; Physics (atmospheric, cosmic-ray, plasma).

New Mexico State University

Applied Mathematics; Applied Work in Antenna Design; Sounding Rocketry and Trajectory Calculations; Astronautics; Biology (stress and survival in extreme environments); Chemistry (high temperatures, thermodynamics, solid state spectroscopy); Electromagnetic Theory; Fluid Mechanics; Gas Dynamics; Heat Transfer (radiative); Optics; Physics (atmospheric, plasma, solar energy); Space Communications Systems; Structural Design; Structural Mechanics.

Ohio State University

Astronomy; Biochemistry; Chemistry; Engineering (aeronautical, astronautical, ceramic, electrical, mechanical, metallurgical, nuclear, mechanics); Geodetic Science; Geology; Microbiology; Mineralogy; Physics; Physiological Chemistry; Physiology; Psychology.

Princeton University

Astronomy; Astrophysics; Biology; Chemistry; Flight Mechanics; Gas Dynamics; Geophysics; Jet Propulsion; Physics (atomic, molecular, plasma).

Rice University

Auroras; Gamma-Ray Astronomy; Geomagnetism; Infrared Astronomy; Interplanetary Medium; Solar-Terrestrial Relationships; Stellar Evolution and Astrophysics; Van Allen Radiation and Cosmic Rays.

University of Rochester

Astronomy; Biochemistry; Biology; Chemistry; Engineering (aerospace, biomedical, chemical, electrical, mechanical); Geology; Optics; Pharmacology; Physics; Physiology; Psychology; Radiation Biology.

Southern Methodist University

Anthropology; Economics; Engineering (electrical, mechanical); Geological Sciences; Mathematical and Experimental Statistics.

Stanford University

Aeronautical Engineering; Biology; Exobiology; Physics; Radio Astronomy; Radio Propagation.

Texas Christian University

Astrophysics; Biochemistry; Earth and Planetary Sciences; Physics (materials, solid state); Psychology (behavioral, learning, perception); Structural Chemistry.

University of Wisconsin

Astronomy; Bacteriology; Biochemistry; Botany; Chemistry; Engineering (chemical, electrical, mechanical, mechanics, metallurgical, mining, nuclear); Genetics; Geology; Geophysics; Mathematics; Meteorology; Physics; Political Sciences; Psychology; Zoology.

Yale University

Astronomy; Biology; Chemistry; Engineering and Applied Science; Geology; Geophysics; Mathematics; Microbiology; Molecular Biophysics; Physics; Statistics.

Present participation in the program includes 40 fellows at 17 universities; they came from 13 countries, as follows:

Belgium	3	Mexico	1
Brazil	1	Peru	1
Republic of China	1	Spain	4
Denmark	1	Sweden	3
France	7	Switzerland	2
Federal Republic of Germany	13	United Kingdom	2
Italy	1		

PART II

Research with Space Vehicles in 1966 and Planned for 1967 - 1968

Astronomy

In this chapter are included reports on recent work conducted with rockets, satellites, and in some cases balloons, involving observations of electromagnetic radiation from celestial sources other than the Sun, Moon, and planets in the short wavelength region of the spectrum (ultraviolet, x rays, and gamma rays), and in the infrared; and plans for future research with space vehicles.

1. ULTRAVIOLET OBSERVATIONS

NASA observational astronomy programs are being carried out both at NASA installations and at universities. The spacecraft, rocket, and balloon observations tend, for the present, to emphasize studies in the x-ray and ultraviolet region of the electromagnetic spectrum.

Two pointed Aerobee 150 flights have been flown by Stecher's group at Goddard Space Flight Center, with a 33-cm f-10 telescope and an attached photoelectric spectrum scanner. The flights (NASA 4.159GG and 4.154GG)* were made at White Sands on July 16 and November 21, 1966. The spectra, observed with three 10-Å exit slits, range from 1100 to 4000 Å. The instrument was programmed to obtain two 20-sec scans of each of five stars. The absolute pointing accuracy was ± 10 to ± 30 arc sec depending on the stellar magnitude. A continuous error signal was provided from which a wavelength correction may be made. The control system uses a three-axis gyroscopic referenced pulse-modulated cold-gas reaction and, for fine pointing, two-axis fine jets referenced to a star tracker. The digital telemetry system allows computer reduction of the data. The stars observed successfully include α Lyr, λ Sco, ξ Oph, α Con Maj, ξ Pup, γ Vel. The spectra show absorption lines and, in the last two stars, strong emission lines. Reduction of these data is now in process.

An experiment designed by Henize of Northwestern University was performed on Gemini 9 while the spacecraft was docked with the Agena in order to use the Agena stabilization system. A total of six star fields were photographed: three with the grating and three with the prism.

*U.S. sounding-rocket launchings in 1966 are listed in Appendix I.

The grating fields were centered on Shaula, Canopus, and Alnilam. The prism fields were centered on Antares, Shaula, and ϵ Orionis. The sequences of six exposures on each field were made according to plan. The lack of strong uv lines in B-star spectra was graphically confirmed. Although the wavelength was adequate to show the forbidden OII emission line at 3727 Å in the spectrum of the Great Nebula and the Balmer series of hydrogen in the spectrum of Sirius, no trace of strong lines appears in the spectra of the O and B stars in the same frame. Current predictions indicate that a resolution about 50 times higher than that achieved will be required to resolve the weak metallic lines in the 2000- to 3000 Å region B-star spectra. The ultraviolet spectrum of Canopus shows considerable detail, similar in most respects to that observed in the uv spectrum of the Sun. The MgII resonance line at 2800 Å is especially strong, lines of MgI (2852 Å) and SiI (2881 Å) are observed, and multiplets of FeI and FeII are prominent below 2700 Å. The Balmer lines and the CaII H and K lines are seen in the blue-violet part of the spectrum. The MgII line is seen in the spectrum of Sirius together with the Balmer series. The Balmer series is seen in the spectrum of Shaula and α Ara. There is also the suspicion that there may be emission lines present in the spectrum of γ Velorum, a fragment of which appears on two of the Canopus plates. Grating spectra were obtained of a total of 99 stars in three fields. About half of these are strong enough to yield quantitative measures of uv-energy curves. Inspection indicates that weak grating spectra are available for early B stars with V magnitudes as faint as 6.0. The well-guided prism spectra show some detail as well. The limits of the hydrogen Balmer series appear, and in F stars the stronger iron multiplets are present. The limiting magnitude of prism spectra has been roughly evaluated in the Orion region. On a 20-sec exposure with reasonably smooth widening, B8 stars down to a photovisual magnitude (V) of 6.5 show useful spectra. On 120-sec exposure with irregular widening, B8 stars with V = 8.2 are well exposed. On both plates, stars about one magnitude fainter show barely visible spectra.

Princeton University Observatory prepared four payloads for launch from the White Sands Missile Range during 1966 to study the ultraviolet spectra of stars. Three flights (NASA 4.50UG, 4.51UG, and 4.176UG) were supported by the National Aeronautics and Space Administration, and the fourth (KP 3.15) was supported by the Kitt Peak National Observatory. On NASA 4.51UG and KP 3.15 the attitude-control system failed to acquire the target, while on NASA 4.50UG the target was acquired but high-voltage arcs disabled the fine pointing system and the data channels.

However, on September 20, 1966, NASA Aerobee 4.176UG was pointed successfully towards Orion and photographs were obtained of the spectra of the OB stars γ , δ , ϵ , ζ , η , θ , ι , and σ Orionis longward of 1130 Å, with about 1-Å resolution in a 3-min exposure (Figure 3-1). The objective spectrograph was a new all-reflective design using a grating and two spherical mirrors to give a 12°-diameter field at f/2. The optical elements were overcoated with lithium fluoride to give highest reflectivity at the shortest wavelengths. Fine stabilization in the dispersion direction to ± 16 sec was obtained with the passive gyro system used on previous Princeton flights.

In the spectra of each of the supergiants δ , ϵ , and ζ Ori the resonance lines of C IV, Si IV, and N V are present in emission at their laboratory wavelengths. Conspicuous uv-absorption lines of these ions are also found though shifted to shorter wavelengths by about 9 Å, revealing shells of gas escaping from these stars at 2000 km sec⁻¹. Also present in the three spectra are the 1207-Å resonance line of Si III and the 1176-Å excited line of C III, both shifted by some 1000 km sec⁻¹ towards the observer, indicating a velocity gradient in the expanding shell. Both the Si IV and N V absorption lines are wide and unsaturated, indicating

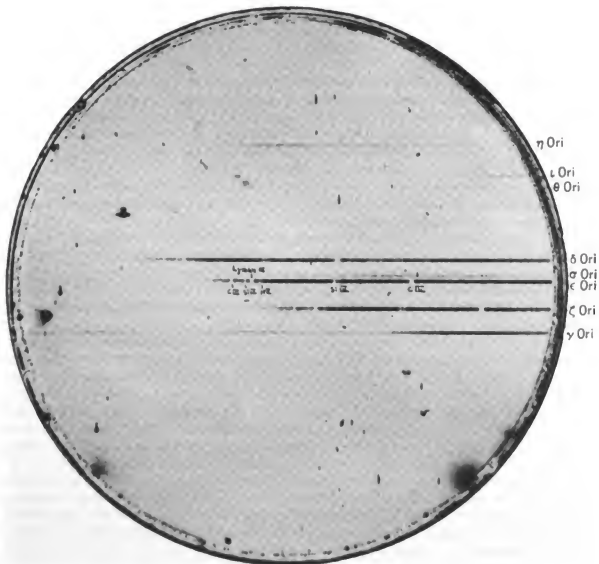


Figure 3-1. Spectra of the Orion stars obtained on NASA rocket flight 4.176UG, September 20, 1966, by Princeton University Observatory.

that Doppler motions must be the prime contributor to the broadening. Morton has analysed the line strengths with a simple model and found a rate of mass ejection of about 2×10^{-6} solar masses/year for each supergiant.

The interstellar Lyman- α absorption line was found clearly in δ , ϵ , ζ , η , ι , and σ Ori with an equivalent width of about $9 \text{ \AA}$ in each case (except perhaps η and σ Ori where it may be 50% wider). An analysis of these lines by E. B. Jenkins gives a column density of 1.5×10^{20} hydrogen atoms cm^{-2} in front of the Orion stars, in contrast with radio observations of the 21-cm emission which give $1.3 \times 10^{21} \text{ cm}^{-2}$ in this direction.

Stone and Morton have studied the interstellar absorption lines of OI, C II, Si II, and Al II found in the ultraviolet spectra of δ and π Scorpii with Aerobee 4.17 flown on June 2, 1965. If the line broadening is entirely by radiation damping, the line strengths correspond to densities of $6 \times 10^{-2} \text{ cm}^{-3}$ for oxygen, 1.5×10^{-2} for carbon, 7×10^{-4} for silicon, and 2×10^{-4} for aluminum. If hydrogen is present in the solar abundance ratio the inferred hydrogen density is a factor 10^2 greater than expected from the 21-cm observations. Agreement with the radio data required some 50 km sec^{-1} of turbulence, and even more if the Orion Lyman- α result is valid in this direction. Perhaps a tenuous, highly turbulent intercloud medium not previously detected is being observed here.

Kitt Peak National Observatory launched two Aerobee rockets (KP 3.11 and 3.19) from White Sands on January 19, 1966, and December 17, 1966, both carrying a spectrometer attached to a scanning telescope of 20-cm aperture. The instrument was designed to obtain spectra of stars in Orion with moderate resolution over the wavelength range 1050 to 2100 $\text{\AA}$. Neither flight yielded useful data because of rocket failures. An additional flight is planned for December 1967.

The University of Wisconsin Space Astronomy Laboratory continued analysis of results of stellar observations at $\lambda 2100$, $\lambda 2500$, and $\lambda 2800$ made in 1964 and 1966 on two unguided Aerobee flights (NASA 4.55 and 4.171). Model atmospheres well represent the continuum of early-type stars in this spectral region; in particular no onset of uv-deficiency setting in at $\lambda 2500$ was observed. Two similar flights (NASA 4.172 and 4.173) are planned for 1967. In addition, a program of direct photography of stars in the ultraviolet was completed using the X-15 experimental aircraft. During the last two flights, daytime photographs were obtained of ϵ Auriga and α Gemini. The data are currently under study at the University of Wisconsin.

Carruthers of the University of Illinois has continued development of ultraviolet image converters at NRL, and had an unsuccessful rocket flight of an objective grating spectrograph and a Schmidt Camera using image intensification. Lack of sufficient altitude and malfunction of the rocket attitude-control system precluded acquisition of useful data. A redesigned experiment is scheduled for launch in 1967.

2. X-RAY AND GAMMA-RAY OBSERVATIONS

A tri-axially stabilized Aerobee 150 rocket (NASA 4.148CG) with a pair of x-ray collimators and proportional counters was flown by a team from American Science and Engineering, Inc. and MIT on March 8, 1966. During the flight the star field at which the collimators were pointing was photographed at 1-sec intervals. Analysis of the data leads to an angular size of < 20 arc sec and the conclusion that the source Sco X-1 is not a filamentary or plasma remnant of a supernova (Gursky et al., *Astrophys. J.* 144, 1249, 1966). Manley (*Astrophys. J.*

144, 1253, 1966) proposed that Sco X-1 was a protostar shedding its magnetic field. This Aerobee flight established the position of the source with sufficient accuracy (Gursky *et al.*, *Astrophys. J.* 146, 310, 1966) that large telescopes could study the area. Detailed photometry and spectroscopy were undertaken at the Tokyo Astronomical Observatory and the Mt. Wilson and Mt. Palomar Observatories. These observations confirmed an unusual object at the predicted brightness. This unusual object appears to be similar to an old nova (Sandage *et al.*, *Astrophys. J.*, 146, 316, 1966). This is confirmed by Johnson and Stephenson (*Astrophys. J.*, 146, 602, 1966).

Gursky of American Science and Engineering conducted another high-resolution survey of celestial x-ray sources to determine their location and flux levels in the range 1 to 20 keV, on NASA 4.149CG from White Sands on October 12, 1966. Proportional counters with collimator scanned selected portions of the sky; several x-ray sources are apparent in the data.

An Aerobee 150 (NASA 4.182UG) was flown by Bowyer of Catholic University from Natal on December 13, 1966, to (1) make a complete x-ray sky survey of the Southern Hemisphere, (2) examine large and small Magellanic Clouds for x-ray emission, (3) obtain preliminary spectral information on any new sources found, and (4) obtain additional spectral information on currently located sources using four x-ray detectors, two of which were large Geiger counters, one a large-area proportional counter, and one a large-area scintillator-photo-multiplier combination, and optical aspect sensors. An initial examination of the telemetry record showed that all x-ray detectors operated in normal fashion. However, both stellar optical aspect sensors failed, which will severely compromise the success of the experiment. It is hoped that a crude aspect determination can be obtained from magnetometer data and airglow horizon indications. Several x-ray signals were observed although the number of sources seen cannot be determined until an aspect reduction is obtained. (This was the first launch from the new Mobile Aerobee Launch Facility (MALF), assembled and installed at Natal, Brazil, by the Sounding Rocket Branch, GSFC.)

The principal work on x-ray astronomy at the U.S. Naval Research Laboratory was the more detailed analysis of the x-ray survey data obtained from the Aerobee flight of April 1965 (see last year's report to COSPAR). Within the galaxy, approximately 25 discrete sources have been located with a positional accuracy of 1.5° ; therefore, identification of the sources in the direction of Cyg A, M87, Cas A, and the Tycho Brahe Supernova of 1572 must still be considered tentative. The observed x-ray flux from Cyg A and M87 was one to two orders of magnitude greater than their radio flux. Comparisons of surveys about a year apart show substantial variations. Cyg XR-1 decreased to one fourth its originally observed flux. Several sources (besides Cyg XR-1, discussed last year) appear to have changed by at least 50% during the 10 months since the previous shot.

Spectral measurements have been confined to simple two-filter photometry. Sco XR-1 has been observed at wavelengths in a 44-to-60 Å detection band, where the flux was comparable to that in the 1-to-8 Å band. A possible interpretation is that the x-ray spectrum consists of at least two components—the black body spectrum of a star and the bremsstrahlung spectrum of its surrounding corona.

Future surveys will be made with standardized proportional counters and repeated often enough to reveal the extent of variability among the observed sources. Observations will be attempted of the extra-galactic sources with much improved positional accuracies to establish the validity of identifications.

Reduction of the data obtained by Lockheed scientists during an October 1, 1965 rocket flight (NASA 4.121CG) has led to the positions of five x-ray sources at low galactic latitude

and longitude, the locations being determined to an accuracy of about $\pm 1^\circ$. The spectral distributions of these sources for photons between 2 and 16 keV are quite similar and can be described in terms of an effective (bremsstrahlung) temperature of the order of 10^8 °K.

Data from three Lawrence Radiation Laboratory experiments in x-ray astronomy carried on sounding rockets have been analysed by Seward and others. The strongest source in the sky, Sco XR-1, was again observed in the energy range 4 to 14 keV on July 27, 1966. Within the accuracy of the experiments this source appears the same in all LRL measurements. The source Tau XR-1, the Crab Nebula, was observed again in the energy range 10 to 40 keV on September 22, 1966. This source too appears unchanged in this energy region since the last measurement. The shape of the spectrum is that expected from synchrotron radiation from very high-energy electrons moving in a magnetic field. This object, the remnant of a supernova of 1054 AD produces a strong, polarized, optical and radio continuum which is also thought to be synchrotron radiation. On September 20, 1966, the source Cyg XR-2 was observed by LRL for the first time. Figure 3-2 shows the measured spectral shape. The x-ray spectrum is similar to that of Sco XR-1. The solid line is a thermal bremsstrahlung spectrum corresponding to a source with temperature $\sim 3.5 \times 10^7$ °K.

The Magellanic Clouds were scanned on September 20 and September 22. These small galaxies are the nearest extragalactic star systems to our own. They are in a region of the south circumpolar sky which is inaccessible to rocket experiments flown from the continental United States. No x rays were observed above background from these objects. A previously unknown weak source was observed but not located precisely. It probably lies in the constellation Vela but could be in the constellation Pupils.

The Sco XR-1 and the Cyg XR-2 sources have been identified in other experiments with blue star-like objects. These have angular diameters of a few arc sec or less and show some of the optical characteristics of old novae. The Crab Nebula is a different sort of object; the x-ray source has a diameter of 1 or 2 arc min and the optical radiation appears to come from an expanding gas cloud having a diameter of several light-years. The x-ray spectra from Sco XR-1 and Cyg XR-2 are similar to each other and different from that of Tau XR-1, suggesting that the x-ray spectrum may indeed be characteristic of the type of source.

A Smithsonian Astrophysical Observatory vidicon spark-chamber experiment to measure the flux, arrival direction, and energy spectrum of primary gamma radiation ($E > 50$ MeV) was successfully flown by a high-altitude balloon to 125,000 ft for 6.5 hr. The balloon was launched at Palestine, Texas, by the National Center for Atmospheric Research. All data from the experiment were telemetered by wideband television to a portable ground station operated by SAO and located at the launch point. The data were recorded on kinescope film and video tape, and are now in the final process of reduction. The data can be grouped into two categories: scientific and engineering. In the scientific category, several possible cosmic gamma-ray sources (e.g., the Crab Nebula and the Sun) were observed to transit the detector; a search will be undertaken to detect radiation from these sources and to measure the spectra. A solar flare of importance 2 also occurred during the flight. The gamma-ray flux and spectrum in the atmosphere as a function of altitude were measured. Additional information was obtained on the nature of the gamma-ray background radiation at balloon altitudes. From an engineering aspect, the use of television to transmit spark-chamber pictures to the ground was evaluated and found to be a very useful technique to employ in gamma-ray astronomy.

Four balloon flights were conducted during 1966 by Haymes and co-workers at Rice University. The balloons carried aloft a scintillation-counter telescope designed to search for radiation with energies between 30 keV and 475 keV from various celestial sources. Hard x rays with

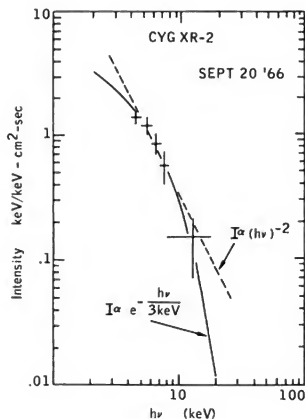


Figure 3-2. Experimental spectra obtained from the source Cyg XR-2 on a September 20, 1966 sounding-rocket flight by Lawrence Radiation Laboratory, University of California, Berkeley. The solid line is the spectrum expected from a thermal bremsstrahlung source with $kT = 3 \text{ keV}$. The dashed line is a synchrotron spectrum with index -2 . The spectrum is probably of the form indicated by the solid line.

an exponential energy spectrum were detected from the Crab Nebula; analysis is continuing on the spectrum above 100 keV. No radiation was detected from the planets Jupiter, Mars, or Venus.

Under the Office of Naval Research Skyhook program, five balloon flights were launched for GSFC in Australia to search for point sources of gamma rays in the 10-to-2000 MeV range using a spark chamber oriented with respect to the geomagnetic field, and an oriented x-ray detector to study specific x-ray sources. Seven balloon flights were launched from Palestine, Texas, including one x-ray telescope flight for NRL, and six flights for the University of Minnesota. The latter, in addition to cosmic-ray studies, included a gamma-ray telescope composed of spark chambers, emulsions, and electronic counters to study energetic gamma rays from point sources, and an x-ray telescope to study spectra of point sources and general galactic background. Five flights were also launched for GSFC from Holloman to locate and study galactic x-ray sources using an x-ray telescope spectrometer, and four launches in Minnesota to search for point gamma-ray sources using gamma-ray spark chambers.

3. INFRARED OBSERVATIONS

Results from the joint rocket program carried out by Cornell University Center for Radio-physics and Space Research and the E. O. Hulburt Center of the Naval Research Laboratory showed an upper limit to the infrared energy density in the universe to be 2×10^{-12} erg cm^{-3} in the 1-to-3 μ region and 2×10^{-11} erg cm^{-3} in the 3-to-7 μ region. The results were obtained with a liquid-nitrogen-cooled telescope (clear aperture 126 cm^2 , field of view 2°) housing an In:As (1 to 3 μ) and a Ge:As (3 to 7 μ) detector.

All major design problems connected with the far-infrared astronomy program at NRL have been solved and it is expected that a rocket containing a liquid-helium-cooled telescope will be flown early in 1967. This flight will employ germanium photo-conductors doped with mercury, copper and gallium, and an indium antimonide detector of the hot electron type to cover the range from about 20 to 1000 μ . It will make use of a specially designed mechanical damper to cause the precession cone of the rocket to expand with time in such a way as to cause the telescope to scan the sky without ever looking toward the Earth. Preliminary estimates of the detector's sensitivity indicate that it should be able to observe the brighter red stars and any background radiation that may exist.

4. PLANNED ASTRONOMICAL SATELLITES

The Orbiting Astronomical Observatories (OAO) are designed to provide an opportunity to explore those regions of the spectrum that are inaccessible to ground-based instrumentation because of atmospheric absorption. The OAO is a precisely stabilized satellite (15 arc sec) designed to accommodate various types of astronomical observing equipment. The primary experiments for the first observatories are concerned with stellar astronomy in the ultra-violet range (800 to 4000 $\text{\AA}$). The observatories will be placed nearly circular orbits at an altitude of 800 km with an inclination of 35° . OAO-A1 was launched on April 8, 1966, and was then designated OAO-1. It achieved orbit and stabilization, but on the second day a failure

in the power subsystem caused the Observatory to fail before any scientific data had been secured.

One of the four experiments consisted of seven telescopes employed in stellar photometry in the radiation region between 1100 Å and 3000 Å. A second was designed to investigate the intensity and direction of arrival of high-energy gamma rays. The third studied x-ray emissions over the entire sky by use of the Geiger counter. The fourth surveyed the celestial sphere for gamma rays in the energy interval from 2 keV to 180 keV. Similar experiments will be used on later flights.

The second OAO, planned for launch in 1968, will contain a Smithsonian Astrophysical Observatory experiment designed to map the sky in four ultraviolet bands of wavelengths 1100 Å to 1600 Å, 1350 Å to 1600 Å, 1600 Å to 2900 Å, and 2400 Å to 2900 Å. The primary objective of this experiment, called Project Telescope, is to measure in each 2°-square field of view the brightness of every star above the equipment threshold, in each of the four wavelength regions, to an accuracy of 0.1 mag. The equipment threshold is approximately 0.04 photon cm⁻² sec⁻¹ Å⁻¹. Approximately 9×10^4 O stars, 6×10^4 B stars, 1×10^4 A stars, and (at longer wavelengths only) 1×10^3 F, G, and K stars will exceed this threshold.

Kitt Peak National Observatory is carrying out a feasibility study to determine the utility of an Orbiting Astronomical Explorer (OAE). Preliminary studies suggest that a three-axis stabilized satellite may be launched from a Scout rocket providing a platform for astronomical instruments with apertures of 45 cm comprising 34 kg of the 125 kg total spacecraft weight. It is expected that the OAE will have a pointing accuracy of about 30 arc sec with closer pointing capability available either by corrective action within the instrument or through error signals derived from the instrument. If the results of the detailed investigation support the encouraging findings of the preliminary study, KPNO hopes to proceed with a proposal for a program that will provide a series of OAE's as a service to astronomers.

The Radio Astronomy Explorer (RAE), the first of which is scheduled for launch in 1967, is designed to measure the frequency, intensity, and direction of radio signals from celestial sources in the frequency range 0.25 to 9.2 MHz. It is to be launched into a circular orbit of 5920-km diameter with an inclination of 58° retrograde. The experiments, designed at GSFC, are intended to (1) investigate galactic phenomena, (2) observe sporadic low-frequency solar radio bursts, sporadic Jovian bursts, sporadic radio emissions from Earth, discrete cosmic sources, and plasma oscillations, and (3) carry out the first mapping of our galaxy at frequencies below the ionospheric cut-off.

Solar Physics

1. ULTRAVIOLET OBSERVATIONS

A number of sounding rockets were launched by NASA during 1966 that performed research in solar physics. On April 14, scientists of the University of Colorado Laboratory for Atmospheric and Space Physics (LASP) measured the profile of the solar hydrogen-Lyman- α line from an Aerobee 150 (NASA 4.24US) launched at White Sands. The instrument used was a high-resolution spectrograph utilizing an echelle as the main dispersing element, and a predispersing grating to reduce scattered light. The effective resolution was of the order of $0.01 \text{ \AA}$. The spectrograph was oriented by a University of Colorado biaxial pointing control. Although the spectrum was faint and somewhat noisy, it clearly showed two reversals, similar to those found by Purcell and Tousey in 1959. The observed asymmetry of the line may be due to instrumental effects. The data on the profile of the solar hydrogen Lyman- α were analysed and the results compared with data on the geocorona's scattered Lyman- α obtained by a LASP flight 8 min earlier. Resonance scattering of solar Lyman- α by H in the Earth's atmosphere appears to account for observed Lyman- α dayglow.

An NRL program, initiated in 1946 to explore the extreme ultraviolet spectrum of the Sun, is continuing. On February 1, 1966, an Aerobee 150 (NE 3.156R) was flown from White Sands instrumented with two normal-incidence spectrographs, λ 490 to λ 2100, two grazing-incidence spectrographs, λ 20 to λ 600, and one spectroheliograph, λ 120 to λ 700. A considerable amount of new data was obtained. Many new spectral lines were recorded in the 33-to-110 $\text{\AA}$ and 490-to-800 $\text{\AA}$ regions, and a number of new spectroheliograms were obtained in lines not previously recorded with the spectroheliograph, in the 250-to-700 $\text{\AA}$ regions—both coronal and chromospheric in origin. Another flight (NE 3.190) on July 27 obtained good data from its two normal-incidence and two grazing-incidence spectrographs, 10 $\text{\AA}$ to 2100 $\text{\AA}$, and its spectroheliograph. Photographs of the Sun were obtained using three unbacked aluminum filters, 170 $\text{\AA}$ to approximately 400 $\text{\AA}$. Disk images and the corona out to approximately one diameter from the limb were recorded. These flights produced new spectra down to C VI at 33 $\text{\AA}$ and extending up to 110 $\text{\AA}$, filling in part of the previous gap 80 $\text{\AA}$ to 148 $\text{\AA}$. Many of the strong lines from 170 $\text{\AA}$ to 200 $\text{\AA}$ have been positively identified as Fe IX through Fe XIII.

A photographic spectroheliograph to record the solar disk in the ultraviolet between 170 and 700 Å, a Cassegrain telescope with 1 arc sec-resolution Lyman-α detector to record variations over solar surface, and a detector to measure total Lyman-α flux from solar disk were flown on April 28, 1966 (NASA 4.189DS). The experiments were conducted by Koomen, Purcell, and Sloan of NRL. Spectroheliograms in uv solar emission lines were obtained with resolution approaching that of ground-based visible light equipment, and plages, prominences, and inner corona recorded in several emissions. The 1 arc sec Lyman-α telescope worked well, but coverage of the solar disk was limited because of small rocket yaw.

On September 2, an Aerobee 150 (NA 3.182) was flown, instrumented by Sloan of NRL with a Cassegrain telescope with a pinhole at the focus and an ionization chamber sensitive to wavelengths λ 1050 Å to 135 Å. Its purpose was to measure how far Lyman-α emission extends beyond the visible limb of the solar disk. Because of the unexpectedly small uv sensitivity, the main experimental objective was not achieved. However, there were about 20 bright peaks in the uv data for which there was measurable signal. These data will be reduced to see if they correspond to any activity regions on the Sun.

A photographic heliograph and spectroheliograph for the uv range 170 to 550 Å, and an ion chamber for recording solar flux at Lyman-α (1216 Å), with data telemetered, were flown from White Sands by Koomen and Purcell on November 12, 1966 (NASA 4.191DS). The heliograph recorded the solar disk containing prominent active regions and inner corona in a uv band 170 to 500 Å. The ion chamber recorded solar flux at Lyman-α.

A spectrograph to measure the profiles of H Lyman-α and H Lyman-β has been constructed and is to be flown in an Aerobee rocket in the spring of 1967. A wavelength resolution of 0.02 Å or better is expected. In addition, a grazing-incidence spectrograph used at 88° angle of incidence and covering 10 Å to 100 Å is being prepared for flight in an airlock fitted into an Apollo command module. It is expected that exposures of 1 hr will be obtained. Wavelength analysis at NRL of the high-resolution echelle spectrograms obtained in rocket flights in 1961 and 1964 is completed and is being prepared for publication. Work is now under way to reduce the echelle spectra to absolute intensities. Investigation of carbon monoxide in the Sun continues. Approximately 14 solar bands of the CO fourth-positive group have been identified, and rotational structure in the solar (1,5) band was studied. Rich of Harvard College Observatory has compared the uv solar spectrum with shock tube spectra of CO obtained under approximately solar conditions. Additional CO bands and rotational structure were identified as a result of this work.

2. X-RAY OBSERVATIONS

On May 20, 1966, Underwood of NASA Goddard Space Flight Center obtained x-ray photographs of the Sun from an Aerobee 150 (NASA 4.95GS). Instrumentation consisted of grazing-incidence x-ray telescopes with plastic and metal filters to define five wavelength regions: 3 to 11 Å, 8 to 20 Å, 27 to 40 Å, 44 to 60 Å, and 44 to 75 Å. The pictures show spatial resolution of about 20 arc sec, and at the longer wavelengths a number of specific coronal features can be identified. At the shorter wavelengths, only the most active regions show appreciable emission.

Neupert of GSFC instrumented another Aerobee 150 (NASA 4.92GS) on May 20 with single crystal, uncollimated Bragg spectrometers for observing the solar soft x-ray spectrum

from 2 to 20 Å and 30 to 60 Å. It is expected to be several months before the data can be processed for comparison with previous observations of this spectral region, but preliminary indications are that line emissions from individual active regions near opposite limbs of the Sun are identifiable.

Unzicker of NRL and Elwert of the University of Tübingen flew a cooperative experiment in an Aerobee 150 flight (NA 3.160) from White Sands on October 4, 1966. Instrumentation included four Bragg crystal spectrometers, two highly collimated x-ray scanning systems and a solar x-ray telescope array with six Fresnel-zone-plate x-ray focusing lenses and sixteen pinhole imaging apertures. About forty x-ray spectrum lines were measured in the wavelength range 6 to 25 Å. Data for spectral solar intensities, physical size of emitting region and location were obtained. Five Fresnel-zone-plate and nine pinhole solar x-ray images were obtained. The data are being reduced.

Solar x rays have been investigated by Aerospace Corporation scientists with instruments mounted on the Earth-oriented, polar-orbiting, Air Force satellite 1965-111B, launched December 11, 1966. A biaxial pointing control, developed by Chater and Howey, permitted the detectors to be fixed on the Sun to within ≤ 1 arc min. Rugge, Walker, and Williams employed a proportional counter for the 4-to-13 Å range, and a scanning crystal spectrometer for the 9-to-25 Å range, both directed at the Sun with this pointing device. Preliminary results with the crystal scanning instrument have yielded the principal lines predicted by Mandelshtam for the region scanned. This includes 6 lines of O VII; the Lyman- α and - β transitions of O VIII; N VII Lyman- α ; 6 lines of Fe XVII; 2 lines of Ne IX; and 1 line of Mg XI. In addition, a number of unidentified lines, particularly between 11 and 14 Å, have been observed. The line spectrum is dominant down to 11 Å. Observations taken 20 days apart (December 15, 1966, and January 4, 1967) show the solar spectrum to vary less than 10% in the relative intensities of the observed lines on these two dates. However, on December 30, 1966, the spectrum was weaker and softer. The oxygen lines at 20 to 22 Å were 30% less intense, and the iron lines at 15 to 17 Å were 50% less intense. Observations made on February 13, 1967, approximately 1 hr after the solar flare of that date, showed a greatly hardened and intensified spectrum. While the O VII line at 21.6 Å was unchanged, the O VIII line at 16 Å was three times more intense, and the iron line at 15 Å four times more intense than the "undisturbed" spectral intensities of January 4, 1967. The Mg XI line at 9.17 Å was also greatly enhanced.

Solrad 8 (or Explorer 30; 1965-93A) was launched by NASA in November 1965 as a U.S. contribution to IQSY. It continues a series of solar x-ray monitors begun by NRL in 1960. Observations during 1966 show a return of the soft x-ray intensity to within 50% of the previous solar maximum and suggest that the coming solar maximum, 1968-69, will equal or exceed the level of activity reached at the previous maximum, 1957-58. Evidence has been obtained that an increase in background solar x-ray emission can be interpreted as a precursor of flare activity and the subsequent disruption of radio communications. X-ray emission accompanying a proton flare in July 1966 showed a time history remarkably different from that of the optical phenomenon and suggests the possibility that x-ray monitoring may provide early warning of energetic particle fluxes hazardous to manned operations in space. The best definition of the sizes of x-ray active regions thus far obtained was derived from observations as the satellite passed through the May 1966 eclipse shadow over Italy. The active regions at the shortest wavelengths were approximately 0.5 arc min in diameter, or about 0.1% of the full area of the disk.

In addition to measuring the intensity and spectral quality of solar flare emission throughout the year, data on daily average x-ray flux was obtained and forwarded to the ESSA

Institute for Telecommunication Sciences and Aeronomy for rapid publication in its monthly bulletin of solar-geophysical data.

The Solrad 9 satellite experiment has been designed, the satellite system has been defined, and construction is in progress. The satellite is scheduled for launch in 1967, into a circular orbit at about 832 km and an inclination of 60 to 65°. It will continue the measurements of Solrad 8 into the ascending portion of this solar cycle. The photometry experiments will have greater dynamic range than earlier experiments, thus permitting "on scale" measurements of 8-to-20 Å and 1-to-8 Å fluxes in quiet periods as well as during flare conditions. Solrad 9 will carry an improved spin-axis orientation system and a core memory of increased capacity.

3. WHITE LIGHT AND INFRARED OBSERVATIONS

A solar-pointed rocket experiment (NASA 4.189DS) carried out by Koomen, Purcell, and Sloan of NRL on April 28, 1966, contained two externally occulted white light coronagraphs placed side by side. They were optically identical except that the focal plane of one was covered with a "concentric" polarizer to record only the tangential component of coronal light. Each coronagraph obtained approximately 40 photographs of several exposure times which recorded the corona from 3.0 to 11 solar radii. Stray light was negligible. Equatorial coronal streamers were recorded to more than 10 solar radii. Many coronal photographs, taken over all parts of the rocket trajectory, contained images of small particles made visible by their strong forward scattering of sunlight. The particles that were close by and were traveling along with but more slowly than the rocket were presumably discharged therefrom. There were also many particles at a distance of several hundred meters as measured by parallax in the two coronagraph fields; these may have originated elsewhere than the rocket vehicle. Mie theory applied to the intensity of the particles indicated that most were in the 10-to-30 μ range.

In a similar flight (NASA 4.191DS) conducted by Koomen and Purcell on November 12, 1966, each coronagraph recorded 64 exposures of duration between 2 and 8 sec; white light corona, streamers, Venus, and the earthlit Moon were within the field of view. One prominent streamer (also recorded in ground-based eclipse photographs) extended to approximately 9 solar radii (Figure 4-1).

Methods and instruments developed in research by Strong at Johns Hopkins University were used in balloon flights sponsored by NASA to study infrared emission from the dust corona of the Sun. Observations were made during and after the solar eclipse of November 1966. The dust was observed to be hotter and hence brighter in thermal emission as it came nearer the Sun; but the radiation fell off and vanished when the dust got near enough to the Sun to vaporize.

At NRL, Feldman of Columbia University designed a Fourier-transform Michelson-interferometer-type spectrometer to observe from above the atmosphere the solar spectrum out to 125 μ. The spectral range of the instrument may be extended to permit observations at submillimeter wavelengths by using a hot-electron photoconductive detector. A flight is scheduled for spring 1967.

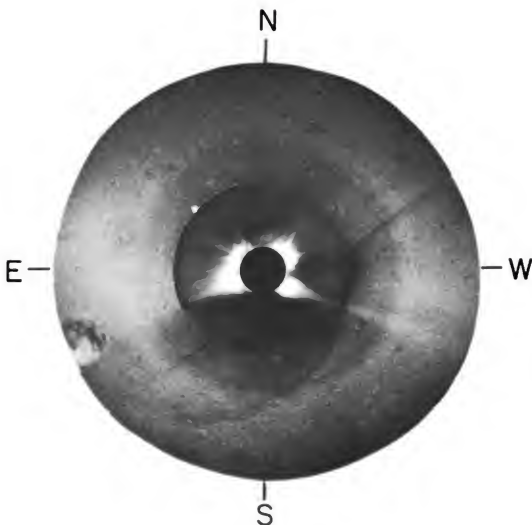


Figure 4-1. Photograph of the solar corona taken with an externally occulted coronagraph mounted on an Aerobee rocket on November 12, 1966, at 0938 MST. Newkirk's Bolivia eclipse photograph is in the center and has the correct scale. Coronal coverage is from 3 to 9 solar radii from the Sun's center. The ring pattern about halfway from the center of the field is stray light. The earthlit Moon is approximately 2° from the Sun. The bright spot on the sunward limb of the Moon is real and is evidently a vestige of the new Moon crescent. The small bright disk is Venus, registered in both Newkirk's and NRL's prints. Both photographs have strong vignetting purposely introduced; this accounts for the apparent uniformity of coronal brightness from center to the edge of the field. (NRL and Gordon Newkirk, Jr., High Altitude Observatory, Boulder, Colo.)

4. ORBITING SOLAR OBSERVATORIES

The Orbiting Solar Observatories (OSO's) are a series of stabilized space platforms, designed to investigate solar phenomena from above the obscuring and distorting effects of the atmosphere. The spacecraft consists of a fan-shaped stabilized section connected by a shaft to a lower rotating wheel-like structure. The wheel contains nine wedge-shaped compartments, five of which are available for scientific instrumentation. The oriented portion of the spacecraft, which carries two compartments for scientific instrumentation, points continuously at the center of the Sun with an accuracy somewhat greater than 1 arc min. The wheel investigations generally relate to sky mapping and to comparing radiation from the Sun with that in other portions of the sky. The OSO's are intended to orbit the Earth in a circular orbit at an altitude of about 560 km inclined 33° to the equator.

On June 3, 1966, after 7 months of inoperation, OSO-2 (1965-7A) was commanded on. It operated successfully until all gas in the pitch bottle was expended, approximately 10 days later. Data reduction and analysis are continuing and scientific papers are expected shortly. OSO-3 (1967-20A) was launched on March 8, 1967.

Three additional OSO's are planned for launch during 1967 and 1968 to carry out investigations of the extreme uv, x-ray, and gamma-ray solar spectrum, survey non-solar x-ray emissions, and measure Lyman- α nightglow and the zodiacal light.

Particles and Magnetic Fields near the Earth and in Interplanetary Space

A major part of the United States effort in space research during the past few years has been devoted to advancing our understanding of the nature and structure of the charged-particle populations in the vicinity of the Earth and in interplanetary space, and to exploring the nature of their interactions with the geomagnetic and interplanetary magnetic fields and with various other aspects of the near-Earth environment. During this reporting period, new findings of special note have been made concerning the characteristics of the magnetosphere and its tail region and possible associations with such phenomena as the aurora and magnetic storms.

1. SPACE VEHICLES CARRYING PARTICLES-AND-FIELDS EXPERIMENTS

During 1966, the National Aeronautics and Space Administration launched four spacecraft carrying large complements of particles-and-fields experiments: the Orbiting Geophysical Observatory satellite OGO-3 (1966-49A), launched on June 7; Explorer 33 (or IMP-4; 1966-58A), launched on July 1; Pioneer 7 (1966-75A), an interplanetary space probe launched on August 17; and the Applications Technology Satellite ATS-1 (1966-110A), launched into synchronous orbit on December 6. The U.S. Air Force in their OV (Orbiting Vehicle) series launched four satellites carrying particles-and-fields experiments: OV3-1 (1966-34A), launched April 22; OV3-3 (1966-70A), launched August 4; OV1-9 (1966-111A), and OV1-10 (1966-111B), both launched December 11, 1966.

In addition to these spacecraft, useful data were obtained in 1966 from the following, launched in previous years: OGO-1 (1964-54A), OGO-2 (1965-81A), Explorer 25 (1964-76B), Explorer 26 (1964-86A), Explorer 28 (1965-42A), Pioneer 6 (1965-105A), Mariner 4 (1964-77A), Relay 2 (1964-03A), 1963-38C, 1964-45B, and OV1-2 (1965-78A).

It is worth remarking that the NASA space probes Mariner 4 and Pioneers 6 and 7 were all returning useful scientific data on particles and fields from different parts of the solar system during 1966. On January 1, 1967, Mariner 4 was at about 1.6 AU from the Sun, about 100° ahead of the Earth; Pioneer 6 was at 0.9 AU, some 60° ahead; and Pioneer 7 was at 1.1 AU, about 15° behind.

The space vehicles launched during 1966, and launches planned for 1967-68, are described below.

Orbiting Geophysical Observatories. The OGO's are a series of standardized spacecraft incorporating active three-axis stabilization and accommodating up to thirty scientific experiments to make correlative studies. On June 7, 1966, NASA launched its first completely successful OGO. Designed to study phenomena in the trapped radiation region and beyond, it was placed into an eccentric orbit (apogee 122,000 km, perigee 295 km) with an inclination of 31° . Whereas the first two OGO satellites have carried out their experiments successfully, neither maintained the desired three-axis stabilization for the planned 30-day period. OGO-3, on the other hand, achieved three-axis stabilization without difficulty on June 10 and continued to operate in the fully stabilized mode for 46 days. Following the loss of attitude control it was commanded into the preplanned alternate spin mode and continued to acquire experimental data. Like its two predecessors, OGO-3 was shaped like a box 1.8 m long and 0.9 m to the side. Two winglike solar-cell panels extended laterally, each 1.8 m wide by 2.3 m long. Two booms reached out 6.7 m to keep the magnetometers well away from the main body. Two box-like packages carrying additional experiments also extended from the main body. The attitude control of OGO-3 served to keep the bottom section always pointing towards the Earth. Infrared horizon scanners provided the necessary error signals while inertia wheels and gas jets provided torques about the roll and pitch axes. Error signals for the third (yaw) axis were provided by Sun sensors.

The payload of OGO-3 comprised 21 experiments selected to investigate space at great distances from the Earth: cosmic-ray detectors, plasma probes, trapped particle sensors, magnetometers, VLF radio-propagation instruments, cosmic-dust detectors and a gegenschein experiment.

Three additional Orbiting Geophysical Observatory flights are planned in 1967 and 1968. The OGO-D and -F missions are to be placed into polar orbits with apogees of 925 km and perigees of about 370 km to study the interrelationships of particle activity with auroral and airglow phenomena, the magnitude and fluctuations of the geomagnetic field, the neutral and ionic composition of the upper atmosphere, and the electromagnetic energy sources contributing to ionization and atmospheric heating. A major objective of these missions is the detailed study of the near-Earth environment during the period of increasing solar activity and at solar maximum.

The orbit for the OGO-E flight will have an apogee of 148,000 km and a perigee of 280 km. The satellite is to carry 24 experiments which, as an entirety, will investigate particles having energies ranging from a few eV to 10^{12} eV. This includes the total spectrum of significant particle populations within the magnetosphere and the solar plasma. Associated with these investigations will be detailed studies of electric and magnetic fields, VLF radio noise, galactic emissions, and other electromagnetic emissions in the uv and x-ray bands.

Interplanetary Explorers. The fourth spacecraft to be flown of the class known as Interplanetary Monitoring Platforms (IMP), Explorer 33 (1966-56A) was launched on July 1, 1966, into an eccentric orbit ranging from 16,000 km to 477,000 km, with an inclination of 29° . The IMP satellites are designed primarily to study the radiation environment of cislunar space throughout a solar cycle in order to obtain information concerning the hazards to astronauts in manned space flight as well as data of intrinsic scientific interest. The region covered is from inside the magnetosphere to beyond the Moon's orbit. Explorer 33, like its predecessors, was a

93.5-kg craft, spin-stabilized, with attitude sensors. Its six experiments included magnetic-field measurements with fluxgate magnetometers; detection of low-energy electrons; detection of both positive ions and electrons in the solar wind; a radio-propagation experiment for total electron content between the spacecraft and Earth; and studies of solar cosmic rays and x rays.

Two further IMP's are scheduled for launch during 1967 and 1968 carrying experiments preponderantly directed to particles-and-fields study. The 1967 flight will also include a micro-meteorite experiment.

Injun Explorer. A simultaneous launch of an Air Density and an Injun Explorer satellite is planned for late 1967. The two satellites are to be injected into a nearly polar, eccentric orbit with a perigee of about 480 km and an apogee of 4320 km. The Injun spacecraft will carry experiments by Van Allen and co-workers at the University of Iowa designed to measure the down-flux of corpuscular radiation into the Earth's atmosphere and to determine the effects of the radiation upon the upper atmosphere. Measurements will also be made of VLF radio emissions in the ionosphere in an experiment conducted by Sagalyn and Smiddy of AFRL.

Owl Explorers. The Owl Explorer satellites, being designed and fabricated by Rice University under the direction of O'Brien, are intended to study near-Earth atmospheric phenomena, particularly the characteristics of aurora and of the airglow as they correlate with the trapped radiation belts and precipitated radiation. Diurnal and conjugate effects are to be investigated. Two identically designed and equipped satellites will be launched by NASA one month apart in late 1967 or early 1968. Each will be placed in a circular orbit at altitudes of approximately 800 km and 700 km, respectively, with an inclination of 80° . The two orbits will have coincident lines of nodes. The satellites will differ in the directions of their magnetic axes. While one Owl views the Northern Hemisphere, the other is to view the Southern.

Pioneer Interplanetary Probes. Pioneer 7 (1966-75A), launched on August 17, followed its 1965 predecessor Pioneer 6 (1965-105A) to carry out a complementary survey of space (Figure 5-1). Whereas Pioneer 6 went into an orbit around the Sun that keeps it inside that of the Earth, Pioneer 7 was placed in an orbit that remains outside that of the Earth, having a perihelion of 1.01 AU and an aphelion of 1.125 AU. Pioneer 7 is a drum-shaped box, 89-cm high and 94-cm in diameter, weighing 64 kg. It is spin-stabilized at 60 rev/min with the axis normal to the plane containing the spacecraft-Sun line and the spacecraft-Earth line. It was made as clean, magnetically, as possible and has proved to be the cleanest yet flown.

The mission of Pioneer 7 is to study the influence of the Sun on the interplanetary environment. To achieve this goal it carried five experiments: (1) a three-axis fluxgate magnetometer, supplied by Ness of GSFC; (2) a Faraday plasma cup to detect the constituents of the solar wind, both electrons and protons, by Bridge, Lazarus, and Scherb of MIT; (3) a curved-plate plasma analyzer to study the solar wind, by Wolfe and Silva of Ames Research Center; (4) a crystal scintillator to investigate the anisotropy of cosmic rays, both solar and galactic, by McCracken, Rao, and Bartley of the Southwest Center for Advanced Studies; and (5) a radio receiver-encoder-transmitter to determine the total electron count between the spacecraft and the Earth, by Eshleman and co-workers at Stanford University and Stanford Research Institute.

Three further Pioneer flights are planned for 1967-1968. Payloads will consist of a magnetometer, plasma probe, cosmic-ray telescope, cosmic-ray detector, two radio receivers (Stanford experiment, above), and a cosmic-dust detector.

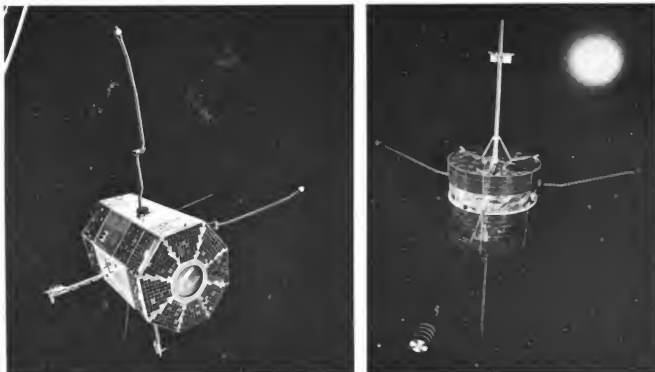


Figure 5-1. Pioneer 7 deep-space probe (left) and the OV3-3 radiation belt and solar flare monitoring satellite (right) (NASA and U.S. Air Force).

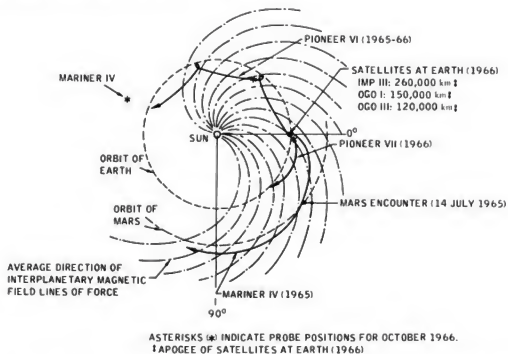


Figure 5-2. Distribution of University of Chicago space experiments on NASA satellites and deep-space probes during 1966 (University of Chicago).

Applications Technology Satellites. ATS-1 (1966-110A) was launched into a synchronous circular equatorial orbit on December 6, 1966. The spacecraft was initially positioned at 151°W longitude. In addition to a variety of technological and meteorological experiments, ATS-1 carried high-energy charged-particle detectors, trapped-particle detectors, a supra-thermal ion detector and a magnetometer. Coordinated ground-based and balloon experiments from the approximate field-line termination area in Alaska are being planned for the spring and summer of 1967. (See Chapter 11 for a description of future launches.)

Mariner 4. Mariner 4 was reacquired in March 1966, after completing a solar occultation, and observations were then made of the effects of solar corona upon the S-band radio tracking signal. The spaceprobe's particles-and-fields experiments include instrumentation to measure interplanetary cosmic rays, solar wind, cosmic dust, and magnetic fields in space. Scientific data are currently being received at a marginal data-error rate. This should rapidly improve in quality as the spacecraft distance from Earth approaches a minimum of 47×10^6 km in September 1967.

U.S. Air Force OV (Orbiting Vehicle) Series. A radiation belt and solar flare monitoring satellite (OV3-3, 1966-70A) was launched August 4, 1966, into an elliptical, near-polar orbit, with apogee and perigee of 4450 and 356 km, respectively, and inclination 81.5° (Figure 5-1). The Aerospace Corporation furnished the following experiments: (1) four omnidirectional detectors for protons from 12 to 130 MeV and electrons from 100 keV to 5 MeV, (2) a three-element solid-state detector for protons in four intervals from 1.1 to 18 MeV, (3) a ten-element solid-state range telescope for protons in eight channels from 25 to 300 MeV, (4) a nine-element solid-state-detector magnetic spectrometer for electrons in nine intervals from 0.20 to 2.4 MeV, and (5) a VLF-radiation detector for the spectral interval from 0.4 to 15 kc. TRW Systems provided a three-axis fluxgate magnetometer, induction coil, and electric field detector to investigate radiation from 20 Hz to 17 kHz.

OV1-10 (1966-111B), a solar atmospheric satellite launched December 11, 1966, into a near-polar, near-circular orbit, was primarily designed for aeronomy studies (See Section 3, Chapter 6); it also carried, however, a heavy primary cosmic-ray telescope and a magnetometer, both by AFCRL, a thermal-control coating experiment by the Air Force Materials Laboratory, and magnetospheric electric-field detector by GSFC. Preliminary data from the heavy cosmic-ray detector indicate satisfactory performance. The alkali-vapor, total intensity magnetometer was boom-mounted to reduce the effect of stray fields. An in-flight frequency counter transformed the magnetometer output to staircase voltages for recording and telemetry. The primary objective of the experiment was the accurate measurement of total magnetic intensity as a function of time and geographic position.

OV3-1 (1966-34A), launched on April 22, 1966, carried four particulate-radiation sensors; a proton spectrometer, an electron spectrometer, a set of electrostatic analysers and a Geiger counter. A malfunction in the proton high-voltage supply occurred at launch destroying the usefulness of this instrument. Another malfunction in the logic of the electron spectrometer limited the data output of this instrument to the intense radiation regions near the equator. The Geiger counter is operating normally and the electrostatic analyser is providing flux and spectral measurements of protons and electrons in the energy interval from 10 to 100 keV.

OV1-9 (1966-111A), launched on December 11, 1966, carried a complete set of sensors designed to measure the spectra, flux, and angular distributions of protons and electrons from 1 keV to 100 MeV. Preliminary results show the instrumentation is working well but no data have been received for analysis.

A three-component fluxgate magnetometer was integrated aboard the OV2-3 satellite, scheduled for a synchronous equatorial orbit. It was launched from Cape Kennedy in December 1965 as part of the payload of a Titan 3C rocket booster. However, a synchronous orbit was not achieved, and the OV2-3 satellite was not ejected. A successor vehicle, OV2-5, is currently being instrumented with a similar group of AFCRL experiments, including a fluxgate magnetometer, for another attempt at a synchronous orbit in the latter half of 1967. Satellite OV1-14 is also scheduled for launch during 1967 and is to carry several particles-and-fields experiments, including an omnidirectional proton and electron spectrometer, magnetic electron spectrometer, and $(dE/dx E)$ and $(dE/dx R)$ telescopes. Studies are also to be made of the flux, spectra, and time dependence of protons and trapped particles, VLF and LF plasma waves, and Lyman- α . (See Appendix II for other OV satellites to be launched in 1967 having experiments of interest to particles-and-fields studies.)

2. PRIMARY COSMIC-RAY STUDIES

This section describes results on primary cosmic rays per se; results which are mostly concerned with effects and energetic solar protons will be found in Section 3.

The Laboratory for Astrophysics and Space Research of the Enrico Fermi Institute for Nuclear Studies, University of Chicago, conducted the following experiments during 1966: (1) three charged-particle telescopes on OGO-3 to study the nuclear composition and energy spectra of all nuclear charges from $Z = 1$ to $Z = 26$ over the general energy range 1 to 1000 MeV/nucleon. (2) A Pioneer 7 experiment similar to that in Pioneer 6, covering the proton and alpha-particle energy range from ~ 1 MeV/nucleon to 200 MeV/nucleon, measuring differential energy spectra and directions of particle arrival near the ecliptic plane. (Figure 5-2 shows the distribution of University of Chicago space experiments on NASA satellites and deep-space probes.) (3) Standard neutron-intensity monitors continued in operation throughout the year at Huancayo, Peru; Climax, Colorado; and Chicago, Illinois. Work is currently under way to compare the absolute-intensity levels of these stations between the two solar minima 1954 and 1965. (4) Aircraft flights carrying a neutron-monitor pile flown previously near the previous solar minimum were placed on board aircraft during 1965 and 1966 under the supervision of Keith with the cooperation of the Sandia Corporation. The results published during 1966 containing new developments dependent upon experimental observations in space or new theoretical results concerning fields and charged particles, are described below.

The individual abundances of the elements helium through silicon, as well as the nuclear-charge group $15 \leq Z \leq 25$ and the Fe-Ni group, have been measured by Comstock, Fan, and Simpson with a telescope composed of solid-state detectors on OGO-1 in the period October 1964 to June 1965. Also measured were the differential energy spectra for He, B, C and O over the energy range ~ 20 to ~ 1000 MeV/nucleon, with some integral measurements above 1000 MeV/nucleon. The spectra for Ne, Mg, and the Fe-Ni group were obtained over a narrower energy range. The experimental results are divided into two time intervals approximately 6 months apart in order to investigate the dependence of abundances and energy spectra upon changes in solar modulation. The abundances of the elements in the kinetic energy range ~ 20 to ~ 330 MeV/nucleon are normalized to oxygen with a flux of 5.4×10^{-3} nuclei $m^{-2}sec^{-1}ster^{-1}$ (MeV/nucleon) $^{-1}$. The ratio of abundances of nuclei with even-to-odd nuclear charge number Z ,

especially in the range $6 \leq Z \leq 14$, is approximately 8:1. The elements Li, Be, and B are present down to the lowest observed energies in the approximate ratio 2:0.7:2.5. The ratio (Li, Be, B):(C, N, O) = 0.26 ± 0.04 . The abundance of the Fe-Ni group relative to C and O is nearly equal to its abundance at high energies. For nuclei $5 \leq Z \leq 14$ the differential energy spectra are remarkably independent of energy below ~ 300 MeV/nucleon. It is shown that the spectra for these nuclei, when extrapolated to the nearby interstellar medium, must be continuously rising toward the lowest observed energies (~ 20 MeV/nucleon) with greater negative slopes than for the He spectrum. Experimental evidence for the galactic origin of these nuclei is presented.

Results of this experiment indicate that some assumptions commonly accepted concerning the origin and propagation of cosmic-ray nuclei are no longer tenable. It appears that energy degradation by ionization loss alone may not account for the results. Two specific alternatives are considered: either that the rate of particle acceleration for a wide range of Z competes effectively with the rate of ionization loss at these low energies, or, alternatively, that a discrete, and possibly nearby, source in the Galaxy could account for these low-energy measurements.

The fluxes and energy spectra of deuterium, protons, and helium were measured on the IMP-3 satellite at a time near minimum solar activity by Fan, Gloeckler, and Simpson. The deuterium differential-energy spectrum in the range 17 to 63 MeV/nucleon is proportional to E^{+2} and, at 60 MeV/nucleon, the relative abundance ratios are $H^2/He^4 = 0.15$ and $H^2/H^1 = 0.05$. If present values of experimental cross sections for the production of H^2 from nucleon interactions with He^4 are used, the observed deuterium abundance may be accounted for by the traversal of He^4 through 4-to-6 g/cm² of matter in cosmic-ray sources and the interstellar medium.

The primary cosmic-ray differential-energy spectra of the two isotopes of helium have been determined in the energy range 40 to 100 MeV/nucleon, over which range the two isotopes were clearly separated. The data from which the spectra were computed by Fan and co-workers have been accumulated over a period of 6 months (June to December 1965) at the time near the minimum of the solar-activity cycle. The measured 3-point He^3 differential energy spectrum can be represented by $dJ/dE = 2.7 \times 10^{-8} E^{+3}$, with units of E in MeV/nucleon, dJ/dE in helium nuclei/(m²-sec-sr-MeV/n). At 90 MeV/nucleon the ratio of He^3 to He^3 -plus- He^4 is $(6.0 \pm 1.5)\%$ and falls off to $(2.0 \pm 0.7)\%$ at 50 MeV/nucleon. Time dependence of the He^3 flux in the 6-month period is examined for solar-modulation effects and the interstellar ratio is predicted for various models of modulation. The implications of these measurements on the propagation of the cosmic rays through interstellar space has been examined and it is shown that, since He^3 is rare in nature, the observed production of He^3 is consistent with an interstellar path length for medium-energy cosmic rays of 2.5 to 3 g/cm².

Badhwar, Deney, Dennis, and Kaplon of the University of Rochester flew a (dE/dX , E)-type counter telescope, consisting of two 1/4-in. thick plastic scintillators 3-1/2 in. in diameter as the dE/dX elements and a 7-in. diameter by 5-in. deep NaI(Tl) crystal as the E element, on a balloon flight from Ft. Churchill on July 29 and again on August 6, 1966. Each flight floated at 2.7 g/cm² of residual atmosphere for about 12 hr and gave the same results. The geometrical factor was 6 cm²sr. The ratio of $He^3/He^3 + He^4$ at 4 intervals between 70 and 240 MeV/nucleon was found to have the constant value of 0.094 ± 0.017 . The proton differential energy spectrum was measured with high precision over the same interval and found to be depressed compared with the intensity at solar minimum in 1965 and to be essentially identical with the intensity observed during 1963. (Mt. Washington neutron monitor = 2320 for 1963,

2450 for 1965, and 2353 for 1966 for data compared.) The He differential energy spectra is depressed as compared with 1965 results of the Chicago group from the OGO satellite. The proton-to-He ratio has been found to be essentially constant and equal to 4 over the range 70 to 240 MeV/nucleon which represents a decrease from a value of 5.7 at solar minimum and rules out a modulation mechanism which is a function only of β (particle velocity). A study of this ratio as a function of R (particle magnetic rigidity) for these two periods also rules out a mechanism which is a function only of R. An $e^{-K/R\beta}$ mechanism is the best fit to the data but it appears that the functional dependence may not be as simple as $f(R\beta)$.

The detector clearly resolves deuterons from protons and an upper limit (due to secondary atmospheric production) of $D/He^4 = 0.25$ is obtained from the interval 50 to 240 MeV/nucleon. The ratio of abundance of light elements to medium elements = 0.21 ± 0.05 is obtained for the energy interval 100 to 230 MeV/nucleon.

The Office of Naval Research in its Skyhook program carried out a variety of cosmic-ray balloon flights during 1966 for several organizations. Six flights were launched from Palestine, Texas for the University of Minnesota consisting of a nuclear emulsion package to study very high-charge nuclei in primary cosmic radiation, a large-area scintillation-counter - gas-Cerenkov-detector telescope to measure high-energy helium and heavier nuclei, and several astronomical experiments. In the Minnesota area, four flights were launched for GSFC to measure primary cosmic-ray particles using a scintillator-photomultiplier detector, and four flights were conducted for the University of Maryland to study the spectrum of helium nuclei and cosmic-ray electrons at northern and intermediate latitudes using a counter hodoscope. A total of 32 flights was made from Ft. Churchill, of which the following relate to cosmic-ray studies:

- (1) University of Rochester, 3 flights (see above)
- (2) JPL, 1 flight, using a spark chamber
- (3) University of Chicago, 6 flights, for measurement of electron-positron ratio by means of a counter telescope, permanent magnet, and spark chambers; and measurement of the primary-electron energy spectrum from 100 MeV to 12 GeV
- (4) GSFC, 3 flights, to study galactic cosmic-ray electrons using a spark chamber, and low-energy galactic cosmic rays using counters
- (5) NASA Langley Research Center, 5 flights, using a neutron and proton spectrometer, emulsions, and ion chamber to measure the radiation component at supersonic-transport altitudes
- (6) University of Minnesota, 3 flights, to study the charge and energy spectrum of primary cosmic radiation using a Cerenkov telescope
- (7) California Institute of Technology, 6 flights, to measure nuclear and electron spectra of cosmic rays using spark chambers and counters
- (8) University of Maryland, 3 flights, to study the spectrum of helium nuclei at northern latitude using a counter hodoscope
- (9) University of California, Berkeley, 13 flights (see Section 6)

New Plastic Detectors for Heavy Nuclei. A new means of detecting low-energy cosmic-ray heavy nuclei has been used at AFCRL. Plastic material may be used to detect heavy nuclei by etching out the dislocations covered by the passage of heavy cosmic-ray nuclei through the material. Cellulose nitrate and other plastics have been flown in balloons, rockets and satellites in contact with nuclear emulsions. Cosmic-ray heavy nuclei with $Z > 10$ have been located

by the etched holes left in the plastics and traced into the nuclear emulsion, where they were identified by track-width measurements and range criteria.

3. THE INTERPLANETARY MEDIUM

This section describes studies of the interplanetary medium, including solar-particle events, propagation effects, modulation of cosmic rays, and the like.

Time variations in the differential energy spectrum and flux of primary helium nuclei in the energy range 30 to 90 MeV/nucleon have been studied by Fan and co-workers at the University of Chicago, over the period from December 1963 to January 1965. Continuous measurements over most of the one-year period were made using (dE/dx, E)-type solid-state charged-particle telescopes which were flown on two satellites, IMP-1 and IMP-2, which had highly eccentric orbits. The helium spectra obtained are well represented by a power dependence of the type $\propto E^{-\gamma}$ where E is the total kinetic energy of the particle. The exponent γ changed from 1.75 to 1.3 in the 1-year period, while the flux of helium increased by about 75% in the same time interval. Since in addition to this observed modulation, the helium nuclei were continuously present, and since the spectrum extends smoothly into the higher energy spectrum measured on balloons, the experimenters are convinced that the low-energy extension of the modulated local-galactic-helium spectrum is being observed. From the measured increases with time of the fractional helium intensity, it is deduced that the modulation depends predominantly on the particle velocity.

Also at the University of Chicago, Gloeckler and Jokipii have determined the diffusion coefficient describing the motion of cosmic-ray particles in the interplanetary magnetic field from the power spectrum of magnetic irregularities observed on space probes. The coefficient is found to be proportional to $R\beta$ (rigidity $\times$ velocity). Near minimum solar activity, only this dependence of the diffusion coefficient on R and β can account for the observed long-term intensity variations of cosmic-ray protons and helium nuclei down to 10 MeV/nucleon. Thus, the motion of cosmic rays in interplanetary space may be quantitatively related to the observed magnetic field.

It has been established recently by Ness and Wilcox that solar magnetic fields carried into the interplanetary medium by the solar wind co-rotate with the Sun and form a sectorlike structure extending as a spiral past the orbit of Earth. The University of Chicago group showed that protons with energies > 1 MeV persist for at least six solar rotations within some of these sectors. It was shown that these protons did not originate in observable solar flares, and their origin is still an open question. On the other hand, even the propagation of solar-flare protons in these interplanetary magnetic-field structures is only partially understood. For example, what role do magnetic-field sectors and their co-rotation with the Sun play in solar-flare particle propagation? To investigate this question it is necessary to study the spatial and time dependence of proton fluxes by making simultaneous particle measurements widely separated in space. These conditions were fulfilled by concurrent charged-particle measurement on Mariner 4 and the IMP satellites. Protons from solar flares and also protons in the recurring 27-day sectors were observed over a range of heliocentric longitudes of 104° and out to distances in excess of 1.5 AU. Experimental evidence indicates that (1) some solar-flare protons are strongly confined to propagate in magnetic-field regions that have the same characteristics as co-rotating sector structures and that these proton fluxes share this co-rotation; (2) the

anisotropic propagation is so dominated by the prevailing magnetic-field structure that differences in heliocentric longitude less than 40° are decisive in determining whether or not solar-flare particles may reach Earth, or any given point in space; and (3) the protons continually observed as 27-day recurring events in earlier experiments are confined to co-rotating regions extending beyond 1.5 AU for several solar rotations. It should be emphasized that these results were obtained under the special interplanetary conditions associated with the minimum in the solar-activity cycle and all effects observed during 1965 are of very small magnitude as compared with the IMP-1 results of 1964.

The Pioneer 6 space probe provides an opportunity for investigating the direction of arrival of particles near the plane of the ecliptic and the time resolution required for observing rapid fluctuations of particle intensity in space. The first test case occurred on December 30, 1965, when protons from a solar flare were detected. Several characteristics of solar particle propagation in magnetic fields—some of which were not anticipated—have been observed directly for the first time by the University of Chicago group. For example, anisotropies in the flux of protons with energies > 13 MeV were large and variable, rapidly changing in direction, and persisting for more than two days after the flare. These anisotropies were due to protons with a differential energy spectrum $E^{-4.25}$ from 13 to 50 MeV. Since the protons are observed to be strongly collimated for most of the time of the anisotropy, it is apparent that even small-scale magnetic irregularities with a scale of $\sim 5 \times 10^4$ to 5×10^5 km are infrequent in the region between the Sun and spacecraft. The highly variable direction of the magnetic field, such as found by Ness and co-workers in 1964 and 1965 with the IMP satellites, would account for the rapidly changing direction of the anisotropy. During part of this event, the proton intensity for energies ~ 600 keV displayed large-scale quasi-periodic bursts with a period of ~ 900 sec and characteristic rise and fall times of about 100 to 200 sec for over 7 hr. The origin of these quasi-periodic intensity fluctuations is not certain, but the possible existence of Alfvén waves in the medium between the Sun and the space probe is an attractive explanation. Simultaneous observations of proton intensity-time distribution in the vicinities of Pioneer 6 and IMP-3 confirm that spatial features in the magnetic field with dimensions as small as 4×10^5 km persist for time intervals of at least 2 hr.

Cosmic-ray detectors designed at the Southwest Center for Advanced Studies to measure the degree of anisotropy of the cosmic radiation in the energy range 7.5 to 45 MeV have been flown aboard the Pioneer 6 and 7 deep-space probes. Results, reported by McCracken, indicate: (1) The galactic cosmic radiation in the 7.5-to-45 MeV energy range is isotropic to within 0.15%. (2) More than 20 examples of cosmic-ray generation by solar flares have been observed during the first nine months of 1966. In each case, there was strong trapping of the solar cosmic rays within the inner solar system. In some cases, the temporal variations of the cosmic-ray flux were extremely complex throughout the events. (3) The cosmic radiation generated in solar flares displays a marked anisotropic behavior, with the direction of the anisotropy suffering definite and abrupt spatial changes. The anisotropy is strong, and the Sun-spacecraft transit times short, even when the parent flare is on the eastern portion of the solar disk. (4) There is a pronounced tendency for a 27-day recurrence of distinct series of intensity variations exhibiting the characteristics of Forbush decreases. These have been seen to be associated with M-region magnetic storms and are interpreted as being due to co-rotating shock waves which exist at the interface of a fast plasma overtaking a slower one. (5) "Energetic-storm particle" events, in which large fluxes of low-energy cosmic rays are detected in association with the passage of a plasma disturbance past the spacecraft, are observed to be coincident with the onset of a Forbush decrease. Studies of the properties of such phenomena have indicated that because the

energetic-storm particle fluxes are characterized by strong unidirectional anisotropies, they are not trapped inside the shock fronts. Studies of the net radial outflow of energetic-storm particles have indicated that particle acceleration occurs within the shock fronts. (6) Definite bidirectional anisotropies exist during the minimum-intensity phase of a Forbush decrease.

The propagation of energetic, charged particles through the interplanetary magnetic field has been theoretically analysed at Boeing by statistical techniques. The transport equation so derived predicts that solar-flare protons with energies > 10 MeV should undergo one-dimensional diffusion constrained predominantly to the magnetic field lines and should exhibit persistent velocity anisotropies directed outward (from the Sun) along the lines. Comparison with balloon and satellite observations of solar-flare protons during the past decade is said to yield quantitative agreement with the theory.

Van Allen and Krimigis at the University of Iowa, and Anderson and Lin at the University of California at Berkeley have measured the fluxes of 40-to-150 keV electrons in interplanetary space following solar chromospheric flares. An examination of the data indicates the following conclusions: (1) Most of the electron events are clearly associated with solar flares. The flares are often accompanied by radio noise and sometimes by x-ray emission. The electrons generally arrive 23 to 55 min after the radio burst, which is reasonable in view of the fact that the unscattered travel-time from the Sun of a 50-keV electron with small pitch angle is 24 min. (2) Flares of 1-, 1, and 1+ importance are able to accelerate and eject large numbers of energetic electrons. (3) The flares ejecting the electron fluxes occur in several different plage regions. Most of these regions are in the Northern Hemisphere and the same plage region can give rise to more than one electron-emitting event. Anisotropies in the observation lead Anderson and Lin to conclude that the diffusion has occurred in the solar atmosphere and that the electrons subsequently escape onto the interplanetary field lines, where they undergo very little scattering.

Comprehensive studies by Anderson's group at Berkeley, taking into account the results of many experiments on space probes and IMP satellites over the past three years, have indicated that the > 40 keV electrons which appear in the interplanetary region following many solar flares fall into two classes: prompt electrons that arrive within an hour of the flare, and delayed electrons that arrive about a day following the flare. The promptly arriving electrons are found to be of two types of events: simple (S) events, associated with solar flares that occur in the absence of large-area Type 1 radio-noise storm, and complex (C) events resulting from flares beneath these large radio-noise regions. The propagation of energetic solar-flare electrons to the Earth is best described in terms of cones of propagation. In the S-events the cones have opening angles of about 30° whereas in the C-type events the cones open to about 90° full angle. Outside the boundaries of these cones the electron flux is much reduced. Within the cones there is a net streaming of the electrons away from the Sun. Solar-flare electron fluxes do not show filamentary structure even at times when protons from the same flare do. This suggests that the electrons are injected into the interplanetary field from regions distinct from the proton-injection region. The delayed solar electron events are accompanied by large fluxes of protons > 500 keV. These events are sometimes closely related to a sudden commencement.

The Stanford radio propagation experiment on Pioneer 6 has successfully measured the average electron density in interplanetary space. This two-frequency (50 and 425 MHz) experiment yielded a high value of 17.3 electrons/cm³ and a minimum of approximately 4.0 /cm³. Densities as low as 1.0 /cm³ were occasionally observed; these observations, however, are open to question. The average daytime magnetospheric-electron columnar content above 1000 km was found to be about 3.3×10^{16} /m² during the period from launch to the end of March 1966.

The trajectory of Pioneer 7 took the spacecraft through the magnetospheric wake at a distance of over 5,000,000 km from the Earth. Analysis of the data from the Earth's tail is very preliminary. There is no doubt that some effect of the Earth's magnetic field persists out to this distance ($1000 R_E$). However, a detailed analysis will be required before one can state explicitly whether the effect is a part of the geomagnetic tail or whether it is simply a wake-effect of the Earth in the solar wind. Pioneer 7 was also occulted by the Moon on January 20, 1967, but analysis of the data for this interval has not yet been performed.

4. MAGNETOSPHERE: EXTERNAL STRUCTURE AND INTERACTION WITH SOLAR WIND

Experimental Results. The analysis of data, chiefly from spacecraft reported previously, has resulted in further advances in the understanding of the physics of the magnetosphere. During the period October-November 1964, IMP-1, IMP-2, and OGO-1 were in such positions that data from the MIT plasma detectors on these spacecraft have yielded substantial information on the magnetospheric shock front. On November 15, 1964, IMP-1 was in interplanetary space and IMP-2 and OGO-1 were in the transition region when a magnetic storm began. IMP-1 observed an erratic increase in number density at the onset of the magnetic storm, which persisted well into the following day. While the density was varying, the particle velocity remained constant at slightly over 300 km/sec. When the density decreased, the velocity returned to a constant value of about 450 km/sec. During this time, OGO-1 and IMP-2 observed alternately interplanetary and transition-region conditions. Relative to average conditions, the OGO and IMP-2 observations represent shock-front compressions to about 85%. Similarly on October 24-25, 1964, IMP-2 was in the outbound leg of orbit 15 at a Sun-Earth-spacecraft angle of about 28° when a small magnetic disturbance (a sudden impulse) occurred. Immediately preceding the sudden impulse, the satellite entered interplanetary space. The shock then oscillated back and forth past the satellite until 0300 UT on October 25, 1964. The motion deduced from this data corresponds to an oscillation having a 2.72-hr period and 1.7 R_E amplitude. It has not been possible from these data to determine whether the entire magnetosphere is oscillating, or whether this motion represents a wave confined to the shock front that propagated past the satellite.

A study of simultaneous magnetic-field and energetic-particle records from IMP-1 by Anderson at Berkeley and Ness of GSFC has shown several distinct correlations on the dark side of the Earth which can be interpreted as diamagnetic effects of charged particles. In the geomagnetic tail large depressions of the magnetic field having radial extent $10 R_E$ are observed as the satellite approaches within $5 R_E$ of the neutral sheet. Energetic-electron fluxes appear throughout this region, but show no strong preference for the neutral sheet. In this region, less than 1% of the diamagnetic effect is due to electrons of energy greater than 45 keV. Regions were identified in which increases in electron flux were associated with reductions of about 10 gammas in the magnetic field.

Groups of electrons of energies > 30 keV were observed in the Earth's magnetosheath, at the Earth's bow shock, and in a region extending out to several Earth-radii beyond the shock. These measurements were made by Fan and co-workers at the University of Chicago from November 27, 1963 to February 13, 1964, with a gold-silicon surface-barrier detector on board IMP-1. A comparison of these results with observations made with a University of California Geiger-

Mueller counter on the same satellite shows that both instruments were recording the same electron structures. Since the response characteristics of the two detector systems for counting electrons are different, it is possible to estimate the spectra of the electrons in these groups or spikes by comparing the counting rates of the respective detectors for each spike. For an assumed inverse-power integral spectrum, $F = F_0 E^{-\gamma}$, the value of γ is found to vary from 2.5 to 4.5 over a wide range of intensities and locations in space.

At times of enhanced solar-wind velocity, having a 27-day recurrence, electron spikes out to $\sim 200,000$ km were also observed. To investigate the origin of the electrons in spikes found in the magnetosheath, at the bow shock, and beyond the shock to distances of several R_E , the temporal variation and energy spectra of the electrons in the outer radiation belt, but near the magnetospheric boundary, were also analysed. It was found that the hardening in the energy spectrum of the trapped electrons in the radiation belt follows closely the compression of the boundary of the magnetosphere under the control of the solar wind. However, this change in spectrum was not observed for the electrons in the spikes. For this reason it is argued that the spikes are not groups of electrons escaping from the outer radiation belt, but rather are locally accelerated electrons, possibly by the Fermi acceleration mechanism proposed by Jokipii and Davis.

Counting rates from a solid-state detector in the experiment of Fan, Gloeckler, and Simpson on the IMP-1 satellite have been analysed by Murayama (on leave from Nagoya University at the Fermi Institute) to investigate the spatial distribution of electrons with energies > 30 keV in the geomagnetic tail and in the magnetosheath region surrounding the tail out to $\sim 30 R_E$. The counting rates range from the background cosmic-ray level ($\sim 3 \text{ sec}^{-1}$) up to 10^3 sec^{-1} and have a positive correlation with the K_p geomagnetic-field disturbance index. A multiple correlation analysis was made to investigate the spatial distribution of electrons, with the following results: (1) Within the tail the particle flux is a decreasing function of Z_n , the distance from the neutral sheet as determined by magnetic-field observations on the same satellite by Ness, Searce, and Seek. Z_n is found to be a better parameter for describing the electron distribution than the distance from either the ecliptic plane or the geomagnetic equatorial plane. (2) The radial dependence of the electron flux reported earlier by Anderson is shown to be due mostly to the spurious correlation between the radial distance and Z_n . (3) For a given constant Z_n , the flux is higher near the dawnside magnetospheric boundary than near the center of the tail. In the magnetosheath beyond the boundary of the tail, the electron flux decreases only gradually with increasing distance from the solar-magnetospheric equatorial plane (the XY-plane in a coordinate system in which the X-axis is in the Earth-Sun line and the XZ-plane contains the geomagnetic dipole vector).

Theoretical and Interpretive Studies. Jokipii at Chicago has studied the change in energy spectrum of a group of electrons being convected downwind in the magnetosheath and has constructed a model based on recent observations that the spectra of the energetic-electron pulse in the magnetosheath soften with increasing Sun-Earth-probe angle and with decreasing distance from the magnetopause. It is demonstrated that the change in spectrum may be naturally interpreted as a consequence of more rapid diffusion of faster electrons through the turbulent magnetic field of the magnetosheath. In particular, the magnitude of the change is readily explained if the mean free path is of the order of the electron-cyclotron radius. Other consequences of the diffusion hypothesis are considered.

Jokipii has also extended a model of first-order Fermi acceleration at shock fronts to consider the angular distribution of the accelerated particles. In the model, particles trapped

between a hydromagnetic shock front and a moving magnetic mirror are accelerated by a Fermi process. Scattering of the particles in pitch angle during acceleration was assumed to offset the decrease in pitch angle due to reflection from the moving mirror. In the previous model, the trapped-particle distribution nearly averaged over pitch angle and the scattering was assumed sufficient to keep the distribution nearly isotropic. Here the limit is considered in which scattering is assumed weak, although it is still strong enough to offset the effect of the mirror. An approximate energy spectrum is obtained, and it is found that acceleration may be very efficient when the scattering is small. In particular, a mirror ratio $B_M/B_0 \sim 2$ may suffice to produce the observed energetic-electron spectrums observed near the Earth's bow shock.

Theoretical calculations at the Institute of Telecommunications Science and Aeronomy (ITSA) of the interaction of the solar wind with the geomagnetic field have been extended to include recent satellite data. Magnetospheric-boundary and shock crossings observed by IMP's-1 and 2, Velas 2A, 2B, 3A, and 3B, OGO-1, Pioneer 6, and Mariner 4 indicate, as expected, that the steady-state fluid model must take into account the solar-wind parameters that exist at the time of each pass. Improved experimental methods used to determine average properties of the plasma have made such comparisons more meaningful. Comparison of this model with experimental data must be made under fairly steady conditions in order to eliminate the rather substantial motions of both the shock wave and the magnetospheric boundary under disturbed conditions. Additional time-dependent calculations have been made for the interaction of a blast wave (which precedes a plasma cloud) with the standing shock wave. It may be possible to relate the magnitude of a SC^+ with the known strengths of both shock waves. The SC^- may be due to the expansion of the magnetosheath as the magnetospheric boundary and shock wave return to a new steady-state condition.

A preliminary boundary-layer calculation along a presumably closed (at $10^3 R_E$) magnetosphere has indicated the thickness of this layer to be as much as $1.6 R_E$ far downstream. Energy input to the interior has been estimated. The latter result compares closely with Axford's order-of-magnitude result of 10^{19} ergs/sec for a 400 km/sec solar wind. A more rigorous approach to the free magnetic boundary layer is presently being pursued.

Analysis by Dessler at Rice University of satellite data relative to the generation of magnetic activity showed the possibility of a weak inverse correlation between the size of the magnetosphere and the amplitude of geomagnetic disturbances. However, the data were so scattered as to indicate that, at the first order, there is no correlation between geomagnetic activity and the size of the magnetosphere, which is a measure of the momentum flux in the solar wind. It was also found that magnetic activity does not seem to be dependent on any form of instability at the magnetopause. That is, high magnetic activity can occur when the satellite data indicate the magnetopause is stable.

Geophysical effects of partial ring currents in the magnetosphere were also investigated by Dessler. The current loop for a partial ring current passes through the ionosphere. It was shown that this current could cause significant heating of the ionosphere during periods of enhanced geomagnetic activity. Satellite data were interpreted as indicating the existence of strong currents flowing along magnetic field lines in the magnetosphere. These currents may well be part of the current loop for a partial ring current.

5. MAGNETOSPHERE: INTERNAL STRUCTURE AND DYNAMICS

This section includes studies related to such features as the radiation belts and the "knee" discovered through VLF-propagation work. Studies specifically concerned with precipitation and associated phenomena will be found below in Section 6.

Radiation Belts. Aerospace Corporation scientists have continued to analyse the results of the Air Force radiation-belt satellite, 1964-45A. White has studied the time dependence of the low-energy proton space distributions and differential energy distributions at eight energies in the range 0.17 to 3.4 MeV for the period August 15, 1964 to February 8, 1965. The data were obtained with a directional proton spectrometer in near-polar orbit with a 3765-km apogee and a 270-km perigee. The proton-flux decay constant in the region around $L = 3-4$ where the main concentration of low-energy protons occurs can be expressed as $(1/\tau)(\text{day})^{-1} = (-0.0007 \pm 0.0007) + (0.0033 \pm 0.0009) \ln E(\text{MeV})$. Protons of 0.2 MeV decreased with an apparent lifetime of 150 days, those of 1 MeV were essentially constant, and protons of 2.5 MeV increased with an apparent lifetime of 500 days. The maximum peak heights of the energy distributions decreased by less than a factor of 2, and the energy spectra hardened slightly with time. The positions of the maxima in B-L coordinates remained almost constant. Therefore, the low-energy proton radiation belts were rather stable during the period studied.

Freden, Blake and Paulikas have employed the data obtained with three Air Force satellites, 1964-45A (launched August 14, 1964), 1965-78A (launched October 5, 1965), and 1966-70A (launched August 4, 1966), to investigate time variations of inner-zone protons. Omnidirectional measurements of 40-to-80 MeV protons reveal little or no change in the flux in the heart of the inner zone, $L \approx 1.5$, $B \approx 0.10$, but decreases of up to a factor of 5 at low altitude in the South Atlantic anomaly at $L \approx 1.3$, $B \approx 0.22$.

Paulikas, Blake, and Freden have also examined the inner-zone electron spectra during 1964 and 1965 with omnidirectional detectors on the satellites 1964-45A and 1965-78A, covering energies ≥ 0.8 MeV. At the time of the measurements, the trapped-electron flux was still dominated by artificially injected electrons dating from the Starfish test. In December 1964, the peak flux of electrons with $E_e \approx 4.5$ MeV was located at the magnetic equator at $L = 1.35$; the omnidirectional flux there was $10^6 \text{ cm}^{-2} \text{ sec}^{-1}$. Decay times of electrons ($E_e \approx 4.5$ MeV) at the magnetic equator are 197 ± 22 days at $L = 1.25$, 442 ± 93 days at $L = 1.40$, and 373 ± 67 days at $L = 1.50$. The decay times do not appear to differ significantly for electrons > 1.6 MeV. The electron spectrum above 1.6 MeV softens with increasing L for $L > 1.5$; the spectrum varies only weakly along field lines.

Paulikas and co-workers have also analysed preliminary data of energetic electrons obtained with omnidirectional detectors on the ATS-1 satellite at synchronous altitude near $6.6 R_e$. The satellite is truly synchronous: hence diurnal and other short-term variations appear quite distinct from long-term changes. As expected, the electron fluxes at this altitude exhibit roughly a smooth diurnal variation with a minimum occurring near local midnight. Very energetic electrons ($E_e > 1.9$ MeV) show a larger diurnal variation than do those in the few hundreds of keV region. Spectra are softest near midnight, and the shapes of the minima vary from day to day. Some indication of an anti-correlation between electron fluxes and K_p was found. Superimposed on diurnal effects, order of magnitude changes in 10-min time intervals were found. Other time variations were found roughly appropriate to longitudinal drifts of electrons. Also some very rapid changes (1 or 2 min) were followed by a gradually changing spectrum becoming

richer in energetic electrons. These changes appear to be non-adiabatic so far as the third invariant is concerned.

Beall, Bostrom, and Williams at APL have described the spatial and temporal characteristics of the artificial ("Starfish") radiation zone for a 27-month period extending from October 1963 through December 1965. Data for this study were obtained from instruments aboard the low-altitude, polar-orbiting satellite 1963-38C, and include directional fluxes of mirroring electrons of energies $E_e \approx 0.28$, ≈ 1.2 , and ≈ 2.4 MeV for $1.23 \leq L \leq 1.60$ and $0.16 \leq B \leq 0.23$, and the time- and L-dependence of the spectral parameters characterizing the electron population. It was found that the spectrum definitely softens as L increases and probably softens with time; electron mean lifetimes obtained over the entire period show high-energy electrons decaying slightly faster than low-energy electrons. The data show evidence of a substantial increase in the intensity of trapped electrons $E_e < 1.2$ MeV between October 1963 and March 1964 in the region $1.4 \leq L \leq 1.8$. Results were also compared with theoretical expectations and with available experimental data.

Data from a scintillator phoswich (phosphor sandwich) flown on a rocket probe launched in December 1961 were re-analysed at AFCRL in an effort to obtain pre-Starfish electron data. The fluxes of protons $1 \leq E \leq 15$ MeV, and electrons $0.2 \leq E \leq 1.0$ MeV, trapped in the inner Van Allen belt prior to the high-altitude nuclear test on July 9, 1962, were evaluated and compared with other measurements. The fluxes agreed with published pre-Starfish data.

An analysis of rocket and satellite particle observations by Zmuda at APL have shown that a longitudinal dependence exists for trapped electrons at B-L points extending into the lower atmosphere over the South Atlantic anomaly. The longitudinal variation results from the precipitation and loss of trapped particles drifting through the anomaly and is a regular characteristic of the Van Allen radiation zones. The trapped electrons that collide with atmospheric constituents produce ionization and represent a significant source of local enhancements in the D and lower E regions of the ionosphere. Regions where electron-ion augmentations may be expected are also considered.

Emulsion particle-detectors were recovered from six low-altitude polar-orbiting satellites during 1966. These emulsions are being analysed by Heckman of Lawrence Radiation Laboratory and Space Sciences Laboratory at Berkeley for the energy spectrum, intensity, and east-west asymmetry in the flux of energetic ($E > 58$ MeV), inner-radiation-belt protons detected in the South Atlantic anomaly. These experiments, which are a cooperative effort between LRL and Lockheed, form part of a systematic study on the temporal and solar-cycle variations of the inner-belt protons. Since the beginning of these experiments in late 1962, data pertaining to the properties of the trapped protons have been accumulated from over thirty polar-orbiting satellite missions. Through June 1966, the experimental results have given no significant evidence for changes in the character of the trapped high-energy protons. Between 1963 and 1966, the proton flux has remained constant within the accuracies of measurement, approximately $\pm 10\%$. No changes in the shape of the energy spectrum in $E > 58$ MeV have been detected. And finally, the measured east-west asymmetries in the proton flux can be accounted for by atmospheric losses only.

To deduce atmospheric-density scale heights from the measured flux asymmetries, orbit calculations for 125-MeV protons were made by Heckman to evaluate the atmospheric densities and scale heights experienced by the particle and its guiding center. Rates of energy loss were also calculated, taking into account the dependence of atmospheric composition upon altitude, as given by the Harris and Priester S = 100 and S = 200 models, diurnally averaged, and the Johnson model for solar minimum. The geomagnetic field was described by the 48-term spherical

harmonic expansion of Jensen and Cain. The numerical results show that for 125-MeV protons, whose guiding centers mirror between 200- and 560-km altitude in the South Atlantic anomaly, the effective atmospheric density averaged over the particle's motion is about twice the density averaged over the guiding center's trajectory. Also, the effective atmospheric scale-heights can be 3 to 4 times the scale height of the model atmosphere, depending upon altitude and time in the solar cycle.

Proton-spectrometer data from the Injun 3 and 1963-38C satellites have been analysed for the period August 10 to November 1, 1963 by Bostrom and Armstrong at APL. The spatial distribution and energy spectra in the region $1.6 \leq L \leq 3.0$ have been determined using the four energy intervals 1.2 to 2.2 MeV, 2.2 to 8 MeV, 8 to 24 MeV, and 24 to 100 MeV. Of special interest is the observation of a significant decrease in the intensity of protons in the 1.2-to-2.2 MeV range between $L = 1.6$ and 2.2 following the magnetic disturbances during September 20 to 23. The apparent maximum decrease observed is a factor ~ 5 and occurs at $L = 1.8$. The higher energy channels show no significant change during the entire period considered, although it should be pointed out that counting rate of the highest energy channel (24 to 100 MeV) is too low to verify McIlwain's observations of a factor-of-10 decrease in high-energy ($E_p > 34$ MeV) protons at $L = 2.4$. The fact that the changes occur only for $E_p \leq 2.2$ MeV suggests the possibility of a resonance effect and various mechanisms are currently being investigated.

Analysis of nuclear-emulsion data by AFCRL from polar-orbiting satellites during 1966 showed the 55-MeV trapped-proton fluxes measured at the lower edge of the inner radiation zone in 1965 were higher than 1961-62 measurements even after subtracting the effect of the Starfish high-altitude detonation. The AFCRL measurements are in reasonable agreement with the theoretical predictions of Blanchard and Hess which are based on solar-cycle changes in upper-atmospheric density. The exposure of nuclear photographic emulsions in recoverable satellites is expected to continue for a number of years to define further both the solar-cycle changes in trapped-proton fluxes and the energy spectra.

On August 8, 1966, in an experiment conducted by Filz, an AFCRL Aerobee rocket (AE 3.734) was launched at Ft. Churchill which exposed a large area of nuclear emulsion and passive solid-state detectors to free space. Although only partially successful due to the failure of its doors to close, about 50% of the emulsions were recovered. Measurements of the fluxes of heavy nuclei, protons, and alpha particles are being performed. An anomalous 30-MeV proton flux was observed which is being studied for possible relation to solar or geophysical effects.

Whistler Studies. A study by Carpenter at Stanford Electronics Laboratories of the travel time of whistlers recorded on OGO-1 provided strong support for the hydrostatic distribution of ionization along the field lines in the plasmasphere. A study of ducted whistlers received on OGO-3 showed the first well-defined evidence of ducting, wherein the frequency-time characteristics of whistlers changed discretely with time as the satellite moved through a series of ducts.

Anomalous nose whistlers were also observed on OGO-1 in a region extending 20° to each side of the geomagnetic equator and from $L = 1.9$ to 2.5. These anomalous whistler traces are usually characterized by nose frequencies of 4 KHz or lower, three or more well-defined and individual components, and a component spacing-pattern that depends upon the geomagnetic latitude. An SEL ray-tracing computer program including the effects of ions was used successfully to predict the dispersion, shape, spacing and nose-frequencies of the anomalous nose whistlers. A diffusive equilibrium model of the magnetosphere was used, involving three ions: hydrogen, oxygen, and helium.

6. MAGNETOSPHERE: DISTURBANCES, PRECIPITATION, AND AURORAL PHENOMENA

Solar-Proton Events. Paulikas, Blake, and Freden of the Aerospace Corporation have observed energetic solar-flare particles in the polar regions with instruments aboard the polar-orbiting satellite OV3-3 (1966-70A). They employed a three-element solid-state detector counter-telescope to measure protons in four steps from 1.1 to 18 MeV and four omnidirectional detectors to cover the range from 12 to 130 MeV. These instruments obtained results from both the August 28, 1966 and September 2, 1966 solar flares. At 2000 UT on August 29, the flux of 2-MeV protons was $2.5 \times 10^3/\text{cm}^2\text{-sec-sr-MeV}$, while at 1820 UT on August 30, the flux was $7.5 \times 10^3/\text{cm}^2\text{-sec-sr-MeV}$. In contrast the flux at 8 MeV decreased in the same time period. For the September 2 flare, at about 1945 UT the differential proton flux over the northern polar cap was $470 \text{ cm}^{-2}\text{sec}^{-1}\text{MeV}^{-1}$ at 20 MeV, and $17 \text{ cm}^{-2}\text{sec}^{-1}\text{MeV}^{-1}$ at 100 MeV. The decay time (late September 2 to late September 3) was 3.4 hr at 100 MeV and 19.6 hr at 20 MeV. The energy spectrum is complex and changed shape considerably during the observations. The disappearance of the energetic protons, while the low-energy (~ few MeV) flux is still increasing after time intervals long compared to an assumed transit time, suggests that perhaps two separate proton emissions were observed. Spatial variation of the low-energy protons over the polar cap was observed. In the main, it consisted of (1) a step-like increase on the noon side (the satellite orbit was almost along the Sun-Earth line), and (2) a decrease in the flux near the magnetic pole. These two features are consistent with a picture of the magnetosphere, initially discussed by Dessler and Juday, that has regions of varying accessibility to low-energy (few-MeV) solar protons. If one assumes a long geomagnetic tail (up to ~ 1 AU), perhaps drawn out by interaction with plasma expelled from the Sun at greater than normal velocities, the flux minimum over the magnetic poles then arises because particles reach these lines, located centrally in the magnetic tail, only by diffusion. The step on the noon side may then be associated with the boundary between field lines which close on the sunlit hemisphere and those which are folded back in the antisolar direction.

Gram at Aerospace obtained additional data on the energy spectrum and time dependence of the solar-proton flux during the September 2, 1966 event, employing a ten-counter range telescope on the same satellite, OV3-3. Eight energy levels spanned the range from 23 to 300 MeV. The 29-MeV flux remained nearly constant during a 15-hr period in which the flux at 55 MeV had changed roughly from about 7 to 1 proton/MeV-cm²-sr-sec. The proton flux at 100 MeV was less than 0.1 proton/MeV-cm²-sr-sec and the energy spectrum fell off as E⁻⁴. With a multichannel magnetic electron spectrometer on the same satellite, Vampola found anomalous energetic electrons at high latitudes following the September 2 event. These electrons were not present immediately prior to the flare. An abrupt change in the spectral shape and in the integrated flux of these anomalous electrons was observed in both the northern and southern polar zones. Electron fluxes and spectra were constant on each side of narrow transition regions (less than 50 km wide) with a spectrum of the shape $dN/dE \sim E^{-2.02}$ on the subsolar side, and $dN/dE \sim E^{-2.77}$ on the antisolar side. The ratio of integrated flux (0.225 MeV to 1.375 MeV) on the antisolar to subsolar sides of the transition region was 3.5 at 19 hr after the flare.

The polar-cap absorption event of early February 1965 was the only such event observed within the few months surrounding the sunspot minimum. Extensive data have been obtained on this event by ITSA from antarctic riometer observations, and a comparison has been carried out with direct measurements of the solar-proton flux made by the polar-orbiting satellite 1964-45A. The results indicate that there was appreciable spatial non-uniformity in the pattern

of precipitation over both northern and southern polar caps; this conclusion is consistent with recent space-probe measurements showing a strong collimation of low-energy solar protons along the direction of the interplanetary magnetic field, and with the existence of a direct link between this field and the magnetic field originating in the terrestrial polar caps.

This same event was observed in the polar regions with detectors aboard 1963-38C by Bostrom, Kohl, and Williams of APL. The initial detection of protons occurred during the pass at 1914 UT, February 5, and the maximum intensity of $115 \text{ cm}^{-2}\text{sec}^{-1}$ for $E_p \geq 25 \text{ MeV}$ was seen during the pass at 2103 UT, February 5. The time history of the low-energy protons ($E_p \geq 1$ to 2 MeV) was considerably more complex than that of the higher energy particles. The maximum observed intensity ($E_p \geq 2 \text{ MeV}$) was equal to $775 \text{ cm}^{-2}\text{sec}^{-1}$ at 0232 UT, February 6 and a second maximum was observed following the onset of the magnetic storm on February 6. At higher energies, the particle flux decayed approximately exponentially in time with the shorter "lifetimes" associated with the higher energies. An attempt to fit the time history with diffusion theory using a diffusion coefficient of the form $D = Mr^p$ was moderately successful for $E_p \geq 25 \text{ MeV}$. The spectrum showed a (nearly) monotonic softening with time, and a power law generally provided a better approximation to the spectrum than did an exponential form.

Additional studies of the temporal and spatial behavior of low-energy ($\sim 1 \text{ MeV}$) solar protons during this February 1965 event have also been reported by Williams and Bostrom based on combined data from the near-Earth satellites 1963-38C and Injun-4, and the space probe Mariner 4. An enhancement of low-energy proton intensities was observed at invariant latitudes $\Lambda \geq 80^\circ$ and may be a low-altitude effect of the high-latitude topology of the magnetopause. Comparison of the polar-cap and Mariner 4 observations indicates that the magnetospheric configuration varies as the boundary conditions imposed by the interplanetary medium vary, thereby causing marked structure in the polar-cap proton intensities. Further comparisons of the polar-cap and Mariner 4 observations have implications regarding (1) a filamentary interplanetary-field structure and (2) an extended geomagnetic tail. The study further indicated that particle motion across interplanetary field lines near the solar surface or in the region of the shock front is required to explain the low-energy proton arrival times in the vicinity of the Earth.

Magnetic Disturbances and Relation to Other Phenomena. A narrow, closed, high-latitude region exists where large geophysical disturbances occur at all longitudes simultaneously along what is being called the auroral oval because of its oval shape and association with the spatial distribution of visual aurora. Zmuda and colleagues have reported additional magnetic results obtained with satellite 1963-38C which had a nearly circular polar orbit with altitude about 1100 km. For $0 \leq K_p \leq 1+$ the following values are the averages of the boundaries of the region where transverse magnetic disturbances regularly occur and which is considered here as the auroral-oval region: the southern boundary Λ_S lies around 73° in 0630 to 0830 LT and rises to an approximately constant value between 76° and 77° for 1130 to 1630 LT. The northern boundary Λ_N equals about 76° at 0630 LT and increases to about 80° for the entire period 1230 to 1730 LT. Both boundaries move southward as the planetary magnetic activity increases. The maximum disturbance recorded equalled 560 gammas.

A three-dimensional structure of the storm-producing plasma ejected by solar-flare activity has been constructed by Akasofu and co-workers at the University of Alaska's Geophysical Institute, in a study of characteristics of geomagnetic storms caused by solar flares that occurred at different locations on the solar disk. An intense storm-time radiation belt (the so-called 'ring current') grows only when solar flares occur very near the central region of the solar disk.

Further, a detailed analysis of the field of the storm-time radiation belt has revealed that the belt is greatly asymmetric with respect to the dipole axis; this has been confirmed by a recent satellite. The growth of the storm-time belt is also found to be associated with an intermittent occurrence of both the auroral substorm and polar magnetic substorm. The polar electrojet that causes the polar substorm is found to flow westward along the auroral oval which is the intersection line between the outer boundary of the trapping region and the ionosphere.

Experiments have been designed by AFCRL for flight on Javelin and Nike-Iroquois rockets to study the polar electrojet, detect hydromagnetic waves, investigate acceleration mechanisms for ambient particles involved in auroral excitation, and acquire vector magnetic-field and charged-particle data. These experimental payloads will be launched at Ft. Churchill. Each launching will be made during a magnetic auroral disturbance so that the charged-particle accelerating mechanisms involved in auroral phenomena may be investigated.

A Javelin rocket experiment (AB 19.286) conducted by Vancour of AFCRL was launched at Ft. Churchill on May 1, 1966. The flight occurred during a 500 γ magnetic disturbance and a Type-1 aurora. Data were acquired from all experiments and are currently being analysed. In addition, a Javelin and Nike-Iroquois are being prepared by AFCRL for a November 1967 simultaneous launch to measure smaller fluctuations in the magnetic field.

Detailed experiment design has also been undertaken at AFCRL for a satellite investigation of magnetic-storm phenomena in the inner magnetosphere. Low-energy particle spectrometers, three-axis fluxgate and search-coil magnetometers, and an electric-field meter are planned for flight on a small satellite to be placed in an elliptical orbit with an apogee at 6 R_E , 30° latitude. The planned scientific investigations include: a study of the magnetic-storm ring current; identification of responsible particles by type, energy spectrum, pitch-angle distribution, and time history, together with a study of the distortion of the geomagnetic field caused by the ring current; a study of the development of the early main phase of magnetic storms aimed at observing a rapid growth in low-energy-particle population with parallel growth in magnetic-field distortion and possible occurrence of strong electric fields; a study of auroral events at mid-to-high-latitude portions of auroral field lines to observe precipitating particles, particle acceleration, magnetic- and electric-field changes, and rapid time variations in all of these; and a study of relationships between solar-plasma changes, magnetic storms, auroral displays, and particle accelerations to determine the basic physical mechanism by which energy is transferred from the solar plasma to regions deep in the magnetosphere.

Role of the Magnetospheric Tail. Using data from the polar-orbiting satellite 1963-38C, the behavior of the high-latitude energetic (≥ 280 keV) electron-trapping boundary, Λ_C , at 1100 km was analysed by Williams of APL and Ness of GSFC for the period March 15-June 3, 1964. A sudden collapse of Λ_C to lower latitudes during the onset of magnetic storms, as indicated by K_p and D_{st} , was found to be a characteristic feature of the low-altitude trapped-electron population. The IMP-1 satellite also sampled field characteristics in the geomagnetic tail at this time. Correlated observations of the simultaneously observed behavior during magnetic disturbances of the 1100-km trapped-electron population and of the field strength in the tail in three cases were in agreement, and in one case in disagreement with the latitude decreases that are predicted for an extended geomagnetic-tail configuration. These results are considered to be direct evidence of the important influence exerted by the geomagnetic-tail field in governing not only the quiet-time trapped-particle distribution, but also the behavior of the trapped-particle population during magnetic storms.

The correlation between energetic-electron bursts or 'islands' observed in the tail of the

magnetosphere by IMP-1 and auroral-absorption events observed by riometers has been examined in some detail for the period March-May 1964 by Reid of ITSA and Parthasarathy of the University of Alaska's Geophysical Institute. It appears that nearly all intense electron bursts are accompanied by almost simultaneous absorption events in the auroral regions, and that there is a close relationship between activity in the auroral zones and events occurring in the distant tail, on occasion at distances almost as great as $30 R_E$.

Auroras: Precipitation, Radiation, and Magnetic Effects. Lockheed investigators have analysed data from a three-day low-altitude, polar-satellite flight that took place November 9-11, 1965. For the three days of this flight the ΣK_p magnetic indices were 8_0 , 1^- , and 6_0 . Particle precipitation in the auroral zones was observed by 29 detectors carried by the satellite and simultaneous measurements of the optical luminosity and electron content were obtained from an instrumented B-17 aircraft and University of Alaska ground stations. Stanford Research Institute measured the radar echoes at 139 MHz from the particle-precipitation regions. Auroral-proton spectra above 10 keV were studied for over thirty peak-intensity regions and can be described by exponential functions with characteristic energies from 10 to 25 keV. The auroral electron spectral data could not be fitted by a simple power law or exponential function, but the main energy contributions came from electrons in the 1-to-10 keV region.

From August 19 to September 18, 1966, balloon and rocket launchings were carried out at Flin Flon, Manitoba, and Ft. Churchill, Canada, by Anderson and co-workers from the Physics Department and Space Science Laboratory of the University of California, Berkeley. Their purpose was to obtain further observations on energetically charged particles entering the atmosphere of the auroral zone. This series of flights is an extension of work begun by Anderson in 1957. In 1965 and 1966, sounding rockets were included in the program. The period of the field operations included the time of the greatest solar activity since 1960 or 1961. Several large flares during this time resulted in a long period of greatly disturbed geomagnetic conditions. Several sudden commencements and very high disturbance indices occurred between August 29 and September 9. Good performance of the vehicles and experimental apparatus, combined with good weather for the launchings, permitted collection of a large amount of interesting data.

A total of 17 balloon flights including 11 large-volume balloons was made at Flin Flon, and 13 balloon flights and 4 rocket flights were made at Ft. Churchill. The balloons were launched by the Office of Naval Research under its "Skyhook" program; the rockets were launched by NASA. During a 10-day period when the geomagnetic storms were in progress 23 balloons and 3 rockets were launched. On one occasion 3 balloons and 1 sounding rocket were simultaneously collecting data on the same event. Considering that many of the balloon payloads were quite complex and the balloons large, this represented a very considerable effort. In all, about 400 kg of scientific payloads were launched on rockets and 550 kg on balloons.

An important scientific objective was the correlation of the dumped-particle fluxes with geomagnetic-field micropulsations. A group under Ward from the Department of Mineral Technology at Berkeley set up micropulsation gear at both Flin Flon and Ft. Churchill. Several interesting correlations have been found that promise to shed light on mechanisms for some of the electron precipitation into the auroral zone.

Some of the qualitative results immediately apparent from the data records are the following: (1) Solar protons were detected on August 29-30 and September 2-4. The atmospheric depth of the balloons was about 3 g cm^{-2} , so that protons above 50 MeV were detected. At least a dozen

satellites were also monitoring these events in space. (2) A great deal of electron precipitation modulated at quasi-periods of 5 to 10 sec occurred from 0400 to 0700 LT on several flights. This was associated with micropulsation activity with about the same period. A closely periodic modulation of the electron precipitation at 25-sec periods was also observed. (3) Microbursts occurred on several flights. They occurred mostly as singles and doubles rather than in long groups. They represented a much smaller fraction of the total electron precipitation than in previous years during weaker events.

The balloons and rockets carried detectors and scintillators pointed in various directions, with various cones of acceptance and energy ranges, as follows:

For balloons: (1) FL—8-cm scintillation counter, collimated to the zenith $\pm 60^\circ$ for monitoring electron precipitation. (2) Type FX—Three 8-cm scintillation counter with ten-channel pulse-height discrimination collimated and aimed differently to cover different radii of precipitating regions, for (i) intensity and energy spectrum of bremsstrahlung, from which the intensity and energy spectrum of parent electrons can be deduced; (ii) time variations of intensity of electron precipitation, especially periodic; and (iii) some indication of space-time patterns of precipitation. (3) Type FD—Four 13-cm scintillation detectors with narrow collimation (30 km at 100 km). (4) Type FR—13-cm scintillator with 1×1 km resolution at 100 km. (5) Type FS—5-cm NaI (Tl) scintillation crystal plus Be window, and 15 channels of pulse-height discrimination of x rays.

The instrumentation carried on the four Nike-Tomahawk rockets (NASA 18.18UE through .21UE) was identical; two kinds of experiments were flown to measure the following: (1) Flux, energy spectrum, pitch-angle distribution and time variations of mirroring and precipitating charged particles in the auroral zone. Electrons 1 to 300 keV and protons 1 to 100 keV were measured. (2) The spatial distribution of precipitating electrons over a region approximately 500×500 km by observation, from above, of auroral bremsstrahlung x rays. To accomplish the experiment in (1) above, a variety of detectors was necessary in order to cover the wide energy range. Also, detectors of the same species were pointed out of the rocket body at two or more different angles to cover a wide range of pitch angles. The experiments utilized the following instrumentation:

Type A: electron and proton spectrometers each with six channeltrons (channel electron multipliers) and static magnetic fields to sort the particles into energy boxes at 1, 3, 10, 30, 100, and 300 keV. (A1 is pointed along the rocket axis, A2 along a radius.)

Type B: plastic scintillation counter with four-channel pulse-height discrimination and fast electronics, for electrons precipitating at 40 to 300 keV at various pitch angles.

Type C: four Geiger-Mueller counters with orientation 0° , 45° , 90° , 135° from the rocket axis, to measure pitch angles of electrons with $E > 20$ keV.

Type D: electrostatic analyser and scintillation detector in a single-particle counting mode to measure flux of electrons, protons, and α -particles.

Type E: a pair of x-ray detectors with magnetic shielding to scan a rearward cone (135° from rocket axis) with a resolution of 20×20 km at the 100-km high electron-stopping layer when viewed from 240 km. E1 was a proportional counter for 5-to-20 keV x rays, and E2 a scintillation counter for 20-to-200 keV x rays.

Studies of particle precipitation into the auroral zone were reported by Brown and colleagues at the University of California, Berkeley. Fast pulsations, characterized by half-widths of 2 to 10 sec and temporal spacings of 4 to 30 sec, in the intensity of auroral-zone x rays have been investigated using simultaneous pairs of balloon-borne detectors with spatial separations of approximately 100 to 200 km, launched from Ft. Wainwright and Ft. Yukon, Alaska. Such events,

usually of an hour's duration, occur almost exclusively in the midnight-to-dawn sector (0200 to 0800 LT) and appear preferentially on the equatorward side of the auroral zone. Spectral analysis shows the phenomena to be nonstationary but suggests that quasi-periods of 5 to 10 sec ought to be considered a significant feature of the process responsible for such variations. Cross-correlation studies confirm the limited spatial extent of individual pulsations, on the average, and further indicate the possibility of longitudinal motions. Microburst events, characterized by scores of transient bursts, each of about 200 msec half-width, occur most frequently around local noon, favoring the late morning and early afternoon. There appears to be little average latitude dependence across the auroral zone. Individual events, however, may be quite restricted in latitude. On one occasion, microbursts were observed for the better part of 3 hr at $L = 5.5$ in the absence of similar activity at $L = 6.5$, suggesting a rather localized magnetospheric origin.

Simultaneous measurements by Brown and co-workers of bremsstrahlung x rays and ionospheric absorption in the auroral zone demonstrate the importance of spectral variability in energetic-electron precipitation for the interpretation of D-region effects. Although the observations are generally consistent with present knowledge of upper atmospheric processes, they suggest a less dominant role for nighttime detachment below 70-80 km than has previously been assumed.

In addition, Brown and Barcus have reviewed the present experimental knowledge of electron precipitation in the auroral zone (using observations primarily from riometer, balloon, rocket, and satellite studies), the association of electron-precipitation events with aurora, magnetic disturbances, and the temporal and spatial patterns of the particle bombardment (Space Science Rev. 5, 311, 1966).

Evans of GSFC conducted a series of three Nike-Apache flights (NASA 14.188GE through .190GE) at Ft. Churchill during February and March 1966 to measure the number and energy distribution of electrons in the energy range 1 to 300 keV that produce the visual aurora. The flights occurred during auroral displays and good data, now being analysed, were obtained.

Simultaneous measurements of magnetic and electric fields, low-energy electrons and low-energy protons in a visible aurora were made by Burrows and co-workers at GSFC in two Nike-Tomahawk flights (NASA 18.07GE and .08GE) from Ft. Churchill on March 23 and April 14, 1966. Instruments consisted of a two-cell rubidium-vapor magnetometer, four electrostatic analysers for electron measurements, and a channeltron multiplier with a curved plate electrostatic analyser for proton measurements. A preliminary review indicates that good experimental data were obtained. Additional data analyses are required to determine total experimental results.

The intensity and energy spectra of low-energy protons, helium nuclei, and heavier nuclei present during polar cap absorption events were measured in a series of Nike-Apache experiments (NASA 14.219GE through .221GE) conducted by Durgaprasad and Fichtel at Ft. Churchill on September 2-3, 1966. The emulsions were recovered intact, and data are being analysed.

A Ft. Churchill rocket flight (AE 3.734) into a daytime aurora was carried out by AFCRL in August 1966, during which a successful measurement of the spectrum in the visible region during a magnetically-disturbed period and in the presence of intense sporadic E was obtained. The data have not yet been analysed.

Two additional rockets (AC 15.735 and AF 3.615), one Aerobee and one Astrobee 200, were fired into a visible aurora at Ft. Churchill, on December 14, 1966, to investigate the auroral ionosphere in experiments conducted by Sandock of AFCRL. A unique feature of this investigation was that the rockets were fired 30 sec apart, and each rocket contained many complementary

experiments to make the most complete measurement to date of the relationship between primary auroral particles, light emission, low-energy electrons, and charged-particle parameters. In addition to successful ion mass-spectrometer data, measurements were made of electron and ion densities and temperatures, total energy deposition, complete electron-energy spectrum, x rays, protons, and the auroral radiance of the green and red lines of atomic oxygen. These data will be utilized with previous measurements to develop models of the ionosphere during Class I⁺ and II type auroras.

Current and planned investigations of auroral phenomena by the Department of Space Science, Rice University, include the following: (1) Data from auroral photometers and particle detectors flown on three Nike-Apache rockets at Ft. Churchill in March 1964 were analysed by Cummings, LaQuey, and O'Brien in a study of transit times and detailed temporal variations of the fluxes of electrons causing a visible aurora. Measurements of monoenergetic electrons at selected energies had been made in a PCM digital format every 700 μ sec. (In addition, instruments have been designed and fabricated for two 1967 Javelin rocket launches, one to seek alpha particles in auroras and one to have two identical payloads (twins) successively pass through the same auroral feature.) (2) Photometric surveys of auroras with uniquely sensitive devices placed an upper limit of some 5 to 10% to the percentage of alpha particles in auroral ionic fluxes. Detailed calculations refined the extent of the contribution of proton bombardment to auroral spectra. (3) Detailed designs were completed and much of the scientific instrumentation fabricated and tested for the two Owl satellites. (4) Studies made of the magnetospheric morphology led to a new concept of energetic-particle domains, in which auroral radiation occupies a pivotal role between solar-wind and Van Allen particles. (5) A design-model structure for a magnetically-oriented satellite was built and proof-tested. (6) An electron-proton spectrometer of unique versatility and capability was designed and numerous versions built, tested, and calibrated. The device can make 36 spectral measurements of electrons and protons with energies of 50 eV to 100 keV in less than a second. (7) A satellite "Aurora 1" was designed and built to measure auroral light and the particles that excite it, and to transmit the data in a manner particularly amenable to international collaborative studies of auroras.

Upper-Atmospheric Physics

1. IONOSPHERIC STUDIES WITH SATELLITES

There were no NASA spacecraft launched in 1966 devoted primarily to ionospheres and radio physics. The major sources of new information in these fields during the past year have been Alouette 1 (1962 Beta Alpha 1), Alouette 2 (1965-98A), the three OGO's (1964-54A, 1965-81A, and 1966-49A), Explorer 20 (1964-51A), Explorer 32 (1966-44A), Pioneer 6 (1965-105A) and Pioneer 7 (1966-75A), FR-1 (1965-101A), and the rocket program. Alouette 1 and 2 are Canadian satellites and FR-1 is a French satellite, launched by NASA as part of the U.S. cooperative program.

Topside Sounders. Alouette 1 continues to operate after 4 years, and is still providing data on the upper F region of the ionosphere. Alouette 2 was launched into a higher orbit, with an apogee of 3000 km. This has revealed new information on the ionosphere at high latitudes where, above 1000 km, very low electron concentrations of less than 50 electrons/cm³ are seen frequently, and large day-to-day changes occur in the electron distribution.

A new plasma phenomenon has been observed. A beat between the plasma hybrid- and gyroresonance frequencies is seen on the Alouette 2 ionograms when the local plasma frequency is sufficiently low. This beat provides an important new technique for measuring local electron concentrations of less than 100 electrons/cm³.

At ITSA, Calvert, Van Zandt, and Loftus have completed the analysis of conjugate ducting observed by the fixed-frequency topside-sounder Explorer 20 (1964-51A). In addition to previous conclusions, the occurrence of conjugate ducts is found to be uniform up to 37° magnetic latitude, where it abruptly diminishes. There is some evidence that the ducts are cylindrical. In addition, an explanation of the additional (oblique Z) trace between f_N and f_T is completed. It arises from oblique Z-mode propagation between the satellite and the ordinary ($X = 1$) reflection level. The phenomenon is related to the Spitze predicted by Appleton-Hartree theory, and does not require electrostatic waves.

A partial ionogram with good frequency resolution was produced occasionally by Explorer 20 from the virtual ranges corresponding to the maxima and nulls of the radio-pulse sidebands.

The plasma scale-height near the satellite can be precisely determined from this partial ionogram. Since the time interval between pulses is 0.1 sec, the scale height can be determined at 800-km intervals along the path of the satellite. Reflections from sporadic E are observed by Explorer 20 when the maximum frequency for the E_s layer is greater than the F2 critical frequency. More than 100 good examples of midlatitude E_s have been found. About half of these have been examined in some detail. The average size of a sporadic-E cloud along the satellite path is about 200 km; however, clouds extending over 800 km have been observed.

Electron-density data obtained from Explorer 20 have been compared with auroral echoes obtained in oblique backscatter data at high latitudes. The Explorer 20 data indicate that in the auroral zone a large increase in mean ionization occurs at all heights from F region to 1000 km. Superposed on this general increase are large fluctuations. Similar large fluctuations are observed in Alouette 1 data, and seem to correspond to soft-electron-flux increases as observed with direct-measurement satellites. The southern boundary of the auroral zone agrees well in comparisons between electron-density measurements and oblique backscatter measurements.

The morphology of the electron increases has been studied and agrees well with visual determinations of the auroral oval. To the south of the auroral oval, large decreases (troughs) in electron density are found at night. The morphology of these regions has been studied. The electron scale height does not change radically within the trough, although total content between the F region and 1000 km does, implying that simple expansion does not offer an explanation.

The U.S. Army Electronics Command's Institute for Exploratory Research operates a station to receive data from Alouette 1 and 2 and from forthcoming ISIS satellites. Investigations of ionospheric conditions at midlatitudes near sunset show horizontal stratification at altitudes above the $h_{max} F_2$ although a latitudinal variation is obvious. A sharp drop in density at $50^\circ N$ at all altitudes, thought to be related to the ionization trough, was reported by Muldrew (J. Geophys. Res. 70, 2635, 1965). Scale heights increase with latitude during this period, and form two distinct groups before and after the abrupt density changes at $50^\circ N$. At higher latitudes density scale-height values near sunset at various altitudes above 500 km converge to a single value.

At the Southwest Center for Advanced Studies an analysis was made of the effects of atmospheric winds and electric fields on the ion continuity-equation for the equatorial F region. It was shown that the "equatorial anomaly," as observed by the topside-sounder satellites, can readily be understood in terms of the ion transport caused by these winds and fields.

Radio-Propagation Studies. The Orbis-Low beacon satellite (OV-4-1T, 1966-99D) which was to transmit two watts on 5.006 MHz, 10.004 MHz, and 30.012 MHz, was launched by the Air Force on November 3, 1966 with the Manned Orbital Laboratory (MOL) test. The launch was quite successful and the desired orbit was achieved. However, the Orbis beacon signal was not received and it is now believed that the antenna did not erect. Another attempt will be made as soon as a satellite becomes available.

An exospheric proton gyro-frequency experiment, utilizing a 2.2-KHz receiver to probe for proton gyro-frequency, was flown in the OV1-9 satellite (1966-111A) launched by the Air Force on December 11, 1966. While the satellite and receiver performed as desired, the data have not as yet been reduced. Further ionospheric experiments are to be flown in OV satellites during 1967 (see Appendix II).

A VLF receiver on Alouette 2 has observed the helium whistler for the first time. By adding the information available from the electron and proton whistlers, the abundances of these species can now be found from radio-propagation measurements alone.

Workers at Stanford University and the University of Iowa have investigated new VLF-

propagation modes observed on the OGO and Injun satellites. The data show that, in space, conducted whistlers can be seen that appear to have the characteristics first described by Story in 1953. The observed dispersions of other whistlers show the effects of positive ions, and are consistent with a ray-tracing investigation of Kimura which predicts that the propagation paths can deviate very substantially from the lines of force of the Earth's magnetic field at frequencies below the lower hybrid-resonance frequency, for particular distributions of ionospheric electron concentration consistent with topside-sounder data.

For a two-week period during the summer of 1965, AFCRL took continuous total electron-content measurements of the ionosphere simultaneously at two northern midlatitude sites by measuring the polarization of VHF radio waves from the synchronous satellite Early Bird (1965-28A). The expected good agreement is found in total electron-content values obtained at the two sites when the data are compared on the basis of the same local mean times at the subionospheric points. The local mean-time difference at the two subionospheric points is 32 min. On several occasions, increases of 10 to 20% in total electron content during less than a 20-min period occurred simultaneously at the two sites. The increase in total electron content was attributed to an incoming flux of approximately 10^{13} electrons/sec in an equivalent vertical 1-m^2 column of the ionosphere. Seven clear-cut cases of simultaneous large increases were observed during the two-week period. No unusual solar activity, including enhancement of uv radiation, was reported for the times of the observations. These simultaneous increases are interpreted as either traveling disturbances that all have a phase front nearly parallel to the line between the two subionospheric points or, more likely, an inward flux of electrons from exospheric heights along magnetic field lines into the ionosphere.

Continuous AFCRL observations of total ionospheric electron content over a period of 100 days were obtained by monitoring Early Bird beacon signals. The summer nighttime values showed a continuous decrease with a roughly exponential shape. Good agreement is found when the data are fitted to a theoretical model using an assumed Alpha Chapman profile and an effective attachment-loss law with exponential height dependence. This good agreement with a simple theoretical model and the observed nearly exponential decay implies that little or no incoming electron flux was incident upon the nighttime ionosphere during the period of these observations.

The radio transmissions at 40 MHz and 360 MHz from OGO-1 have been received at ITSA in Boulder and at Stanford University since the satellite was launched in September 1964. This has been the first attempt to measure the electron content of the exosphere by a combination of Faraday and differential Doppler measurements, and although observations have been intermittent because of the orientation and spin of the vehicle, some data show the effect of the plasmopause and others indicate a movement of ionization between the ionosphere and the exosphere near sunrise. Apogee is $24 R_E$ and signals have been recorded from as far away as $10 R_E$. Studies are also being made of ionospheric effects such as scintillation (since absolute phase scintillations can be observed with this system) and large irregularities.

ITSA has also recorded the Faraday rotation of the 40 and 41 MHz signals from Explorer 22 (Beacon Explorer 2; 1964-64A) for two years and, by means of differential Faraday analysis, has recently analysed these data for electron content and large-scale irregularities including statistics of their amplitudes and horizontal extents. Preliminary estimates of the principal characteristics follow. Electron content during the solar minimum is about one-fifth that during the last solar maximum, the daytime maxima having dropped from about 8×10^{17} electrons/ m^2 column (column electrons) to around 1.5×10^{17} , and the minima from 9×10^{16} to 1.9×10^{16} . The irregularity analysis considered only those excursions exceeding 10^{15} column

electrons. Irregularity amplitudes attain maxima of about 4×10^{15} column electrons and average about 2.5×10^{15} . Lengths (horizontal extent) of irregularities appear to average around 190 km, which is somewhat greater than those occurring during the last solar maximum.

Determination of ionospheric electron content by means of Faraday, Doppler, and hybrid methods using satellite signals is actively being pursued at the USAECOM's Institute for Exploratory Research. Simultaneous observations of amplitude, frequency, and polarization fluctuations in the ionosphere are also being emphasized. The Doppler-frequency scintillations present a most sensitive tool for the exploration of ionospheric turbulence and refractive effects. The polarization scintillations, measured second by second with a polarization following system, are useful in exploring the fine-structure gradient of the integrated electron content. The amplitude scintillations are assumed diffraction effects of a grid-like structure of the ionosphere. Such a structure was suggested by polarization-content measurements during a period when simultaneous amplitude and polarization scintillations occurred. Frequency and amplitude scintillations could sometimes be correlated when the grid-like structure was sufficiently pronounced to produce both an amplitude and a phase modulation to a traversing cw signal.

During the week of December 9-16, 1966, when ATS-1 (1966-110A) was being maneuvered into its synchronous orbit, observations were made simultaneously by AFCRL of the amplitude and angular scintillations imposed by the ionosphere on its VHF beacon transmissions. For this purpose, the Sagamore Hill Radio Observatory's 45-m and 25-m antennas at Hamilton, Massachusetts were used in an interferometer configuration. The maximum effective baseline provided by these antennas, together with the overall receiver sensitivity, established a minimum detectable angular deviation of ~ 5 arc sec (rms). For most of the observational period, the orientation of the baseline relative to the satellite resulted in an increase in this figure to ~ 7 arc sec. Circularly polarized feeds were used so as to minimize variations in signal level due to Faraday rotation along the signal path. Scintillation activity was observed sporadically while the satellite was visible above the radio horizon, and both the magnitude and frequency of occurrence of scintillations increased with decreasing elevation angle. There was no one-to-one correspondence between amplitude and angular scintillations; angular scintillations were always accompanied by amplitude scintillations, but not the reverse. When they were occurring simultaneously there was usually a high correlation between the two. Towards the end of the observing period, when the satellite was very close to the horizon, very intense scintillation was observed, apparently characterized by strong focusing. The scintillation behavior indicated rather rapid transitions between the domains of geometric and diffraction optics for a strongly scattering screen, while the scintillations exhibited pronounced periodicities of ≈ 1 min. At these times, the horizontal component of irregular refraction was typically about 3 arc min, and the amplitude scintillation was about 25 dB. The data are presently under study with a view to the possibility of determining the size of the dominant irregularities, their relative inhomogeneity, and their velocity.

A four-station receiving network was established by AFCRL to receive VHF radio signals from a synchronous satellite to study scintillations in the upper atmosphere. Distances in the north-south and east-west directions varied among the various sites from 3.84 km to 10.08 km. Ionospheric motion was measured by recording and correlating the signals that had penetrated the same drifting irregularities at the separated receiving stations. The experiments covered two periods on the Early Bird satellite (136 MHz), with a total of approximately five days operation. A similar period was covered on ATS-1 (136 MHz). Correlation measurements on the Early Bird experiment indicate some possibility of measuring north-to-south velocities but correlation was much more prevalent in the east-to-west direction, with drift velocities in

the range of 56 m/sec to 350 m/sec. East-west scale sizes during a 5-hour scintillating period varied from 900 m to 8 km. The data also revealed a period of coverage by a large irregularity structure of more than 2240 km in the east-west direction.

An analysis of the 2287 hours of 136-MHz signal reception from Early Bird at Sagamore Hill was continued at AFCRL during 1966 to determine the statistical variations of ionospheric scintillations. Scintillation Index was measured for all periods when the index was greater than 5% and the distribution and diurnal variation were determined for the May through August 1965 period. Scintillation indices > 5% were recorded 18.7% of the time and deep scintillations > 75% were observed 0.7% of the time. A comparison with similar measurements for 1944 hours of data from Ghana shows that the equatorially disturbed ionosphere caused scintillations about 10% of the time, but 5% of the time scintillations > 75% were recorded. The diurnal variation of the occurrence of scintillations for the signal received at Sagamore Hill shows two maxima: a predominant peak occurring near midnight with a secondary peak around 1000 LT. The occurrence of scintillation at Ghana shows only the predominant midnight peak. In a joint AFCRL program with the Communications Satellite Corporation, all the Early Bird data has been digitized for computer analysis. The results should not only provide refined estimates of the occurrence of deep fades, but will also indicate the accuracy of the earlier manual reduction of the data.

Statistics on the frequency of occurrence and depth of scintillation produced by ionospheric irregularities are an important parameter in the design of communication systems in the VHF band. Present statistics are quite meager and experimental programs will continue on these aspects. A preliminary statistical review based on simultaneous observations from a cooperative net of stations in the Americas and Europe has indicated a steep latitude gradient with mean nighttime fades at 54 MHz varying from 3 dB at the magnetic equator, to 1 dB at mid-latitudes, to 10 dB near the auroral zone. Further analysis is being made of the latitudinal variation by study of special periods during 1964, 1965, and 1966, using observations from a voluntary worldwide association of observatories, known as the Joint Satellite Studies Group.

Interaction between Space Vehicle and Medium. The first preliminary measurements were made of the ionospheric bow shock produced by a space vehicle, and the wake behind it, during the flights of Gemini 10 and 11 as the astronauts maneuvered their capsule relative to the Agena, in an experiment by Medved of Electro-Optical Systems, Inc. Disturbances of the ambient medium (charged particle densities and temperatures) were detected in a cylindrical volume around the spacecraft about 6 m wide and 30 m long.

2. ROCKET STUDIES IN THE IONOSPHERE

Eclipse Studies. Six boosted-Arcas rockets were successfully launched into the lower ionosphere from a shipboard launching platform off the coast of Greece during the annular solar eclipse of May 20, 1966. The rockets contained Faraday-rotation experiments instrumented by GSFC to examine the progressive changes of electron density during the eclipse, and were part of a cooperative project which included a Greek partial-reflection sounder.

The total solar eclipse of November 12, 1966 was studied by 15 sounding rockets launched by NASA, AFCRL, Army Ballistic Research Laboratories, and the Sandia Corporation at Cassino, Brazil in cooperation with the Comissão Nacional de Actividade Espaciais. In the

first of two NASA programs, a Nike-Apache (NASA 14.77CA-CI) instrumented by L. G. Smith of GCA Corporation was designed to compare the electron-density profile with wind profile. It carried a Langmuir probe to measure electron density and electron temperature on the ascending half of the flight; the wind profile was to be measured by photographing a trimethyl-aluminum (TMA) vapor cloud on the descending portion of the trajectory from the camera sites. Good data are expected from the dc probe, but no photographic results of the TMA cloud were obtained from the ground-based sites or the optical aircraft. In the other NASA program, University of Illinois and GCA scientists collaborated in launching four additional Nike-Apache payloads (NASA 14.274UI, .302UI through .304UI) to measure electron concentration, electron temperature, and uv flux. The cw propagation technique used to measure electron concentration, in which the receiver in the rocket provides, in-flight, a servo-signal for continuously adjusting the amplitude of a transmitter on the ground, has been described by Knoebel and Skaperdas in Rev. Sci. Inst. 37, 1395 (1966). Preliminary evaluation of results indicates that many valuable data were obtained although there was some difficulty with the ion mass spectrometer in the second flight (NASA 14, 302UI), which also carried a Brazilian euv electrometer experiment.

The four BRL flights, instrumented by Pennsylvania State and Cornell Universities, employed Nike-Javelin rockets, and the payloads consisted of a parachute-borne blunt probe to measure conductivity, a Langmuir probe to measure electron temperature and density, a receiver for a 185.5-kHz absorption experiment, and a 2.4-MHz receiver to aid in the calibration of the Cornell Aeronautical Laboratory's partial reflection experiment. Earlier flight tests of the blunt probe and Langmuir probe were made at Eglin AFB, Florida, in August and September, and a calibration flight of the entire payload was made at Cassino on November 5. Launchings during the eclipse took place at T - 32 min, T - 2 1/2 min, T + 40 min, and T + 85 min where T was 1410 UT, the time of totality. For the T - 2 1/2 min flight, eclipse-related effects are clearly evident in the data from each of the experiments. The parachutes on the flights failed to operate properly, but data obtained near apogee were quite usable. At 70 to 80 km, the electron density did not decay to the nighttime value at totality. The low-frequency continuous radio-wave propagation experiment consisted in measurements of the maximum horizontal radiated magnetic-field component of a transmitted wave obtained from a short vertical electric dipole antenna on the ground. The aim of the experiment was to measure electron density in the D region during various phases of totality. Data were successfully obtained during all flights and are presently being analysed with the aid of computer solutions of the wave fields in the ionosphere.

The Sandia payloads, carried by three Nike-Tomahawk rockets, consisted of fixed-station curved-crystal spectrometers, eight to a package, to map solar x rays at various stages during the eclipse, and to correlate emission lines of highly ionized C, N, and O₂ in the 16-to-44 Å range with visible active centers on the Sun.

Four AFRL Nike-Hydac payloads, consisting of a pumped quadrupole mass spectrometer and six other experiments designed to measure ion and electron densities and temperatures, x rays, and Lyman-α were also fired during the expedition. One rocket was fired a week before the eclipse, on November 5; and three rockets were fired on November 12, respectively, 16 min before totality, during totality, and about 13 min after totality (mass-spectrometer failure). The first and third rockets were fired so that the Sun was 80% obscured when the rocket was ascending at 90 km, and the second rocket fired so that the rocket was ascending at 100 km at the center of the eclipse during totality. Preliminary trajectory data indicated that the rockets attained altitudes of approximately 115, 95, and 115 km, respectively. Successful measurements

were made of the ion mass (3 of 4 rockets), ion density (4 of 4 flights), electron density (4 of 4 rockets), x rays (2 of 4 rockets) and Lyman- α (4 of 4 flights). Positive ion-composition data were obtained between about 70 to 115 km both on rocket ascent and descent. On all three flights the ions of 19^+ , 37^+ and 55^+ ($H.(H_2O)^+$) were detected below 82 km and found to disappear above this altitude. From 82 km to 115 km the metal ions were again detected with iron and magnesium predominant; the metal ions exhibited layered structure most similar to earlier results obtained by AFCRL in the Northern Hemisphere. However, the most abundant ions above 82 km were NO^+ and O_2^+ , and the abundance of these ions was found to decrease significantly during totality. The concentration of iron ions showed no apparent decrease during totality, but magnesium ions showed some reduction in concentration. These results, when completely analysed and correlated with the many other measurements obtained during the solar eclipse, should make a significant contribution to understanding of the physics of the lower ionosphere.

Theoretical models of the behavior of the atmospheric constituents in the D and E regions were developed by AFCRL for the November 12 eclipse. These models of individual charged and neutral species were calculated with a computer technique for solving a set of 15 simultaneous differential reaction-rate equations coupled with a set of 15 simultaneous exponential equations. Between 90 and 120 km the change during the eclipse was due to dissociative recombination which produced a time delay between the maximum of the eclipse and the minimum of the electron density. Because the time constant for this process increases as the altitude decreases, there is an increase in the time difference between maximum eclipse and minimum electron density. Below 80 km the time delay disappeared because the effect was no longer due to dissociative recombination but to the absence of rapid photodetachment.

Other Rocket Studies. The University of Illinois, University of Michigan, and GCA Corporation have continued a cooperative investigation of the D and E regions of the ionosphere, principally by measurements of differential absorption, Faraday rotation, and electron probe currents from Nike-Apache rockets launched under the sponsorship of NASA. During 1966, the following flights were made: (1) NASA 14.248, launched from Wallops Island, on January 10, 1966, a winter day of anomalously high absorption, revealed an electron density at 82 km of about ten times that on a normal winter day. (2) NASA 14.270UI was launched from Wallops Island on June 14, 1966 during a sunrise period of high VLF absorption of 21.4 kHz signals originating at NSS in Annapolis, Maryland. In a continuing series of lower ionosphere investigations, the University of Illinois/GCA group has systematically fired rockets into the E region near sunrise. Results reported by L. G. Smith showed that the presunrise increase in E-region ionization coincides with the onset of illumination of that region by Lyman- α . In the altitude range 130 to 150 km, nitric oxide concentrations of $8 \times 10^6 \text{ cm}^{-3}$ were also deduced, in good agreement with theory. (3) Flights 14.271UI through .273UI were designed to measure recombination coefficients of major E-region constituents and to investigate the importance of metallic ions in the lower ionosphere at solar zenith angles of 85° , 102° , and 112° , respectively, at sunset of one day. NASA 14.271UI (Wallops Island, August 24, 1966) was the first flight of a positive-ion quadrupole mass spectrometer designed at Illinois' Charged Particle Laboratory. Developmental instrumentation problems were encountered. NASA 14.272UI carried a University of Michigan Nagy spherical ion trap and a Smith-Boyd-Druyvesteyn electron temperature probe on two booms in addition to the usual propagation and electron-current experiments. An in-flight partial failure of the telemetry transmitter made it necessary to recover data from this shot by use of phase-locked discriminators. The flight of 14.273 was postponed for modifications of the mass spectrometer.

On January 5, 1966, Penn State University's Ionosphere Research Laboratory flew two Arcas rockets with parachute-borne blunt probes at night from White Sands. These experiments, reported at the May 1966 COSPAR meeting, succeeded in separating positive and negative charged-particle conductivities in the altitude range 50 to 80 km. The conclusions were that there were essentially no free electrons in this altitude range at night, with a ratio λ of negative ions to electrons of at least 500 at 80 km, increasing at lower altitudes. The ion-density profiles deduced from the data indicated that the region could be explained by a rather simple model involving a constant ion-ion recombination coefficient. Daytime blunt-probe experiments were also flown on Arcas rockets on January 6, August 29, December 12, and December 13 from White Sands. They were intended primarily for instrumentation development, but data from the shot of December 13 indicate that, in addition to conductivity and ion density, the quantity $(\lambda/\alpha e)$ can be deduced directly from the data, where αe is the electron-ion recombination coefficient.

Two additional Penn State blunt-probe experiments were launched at night during a PCA event at Ft. Greely, Alaska, on September 6-7. One of the parachutes failed to function, but data from the other experiment showed a greatly enhanced ionization, nearly constant with altitude.

A Black Brant rocket (AC 17.604D) was flown into an auroral absorption event (1.5 dB) on September 28, 1966, at Ft. Churchill by AFCRL. The rocket payload was successfully tested and will be used with minor modifications in four AFCRL rocket flights into PCA events planned for 1967. Instrumentation included retarding potential analysers, Gerdien condensers, rf probes, Langmuir probe, Geiger counter, scintillator, propagation experiment, Lyman- α detector, and a photometer. The rockets to be fired into PCA events during 1967 will be launched simultaneously with rockets carrying mass spectrometers.

In a joint program between Southwest Center for Advanced Studies and ITSA, further rocket launchings were made in the series of studies called Multiple Ionospheric Probes (MIP). A nighttime flight on April 8, 1966 (NASA 14.76UI), with electron densities some 30 times lower than the 1965 daytime flight, indicated that the general behavior and operation of all the probes was very much the same. Good resonances were obtained with the resonance-relaxation probe down to 200 kHz. The main resonance in the impedance of an 11-cm sphere remained above the electron cyclotron-frequency, as did the resonance-rectification effect. The sheath correction indicated by the high-frequency capacitance probe was slightly greater, being 2.3 for an electron density of $2.2 \times 10^3 \text{ cm}^{-3}$ as compared with 1.7 for $6.1 \times 10^4 \text{ cm}^{-3}$. Results were reported by Heikkilä at the May 1966 COSPAR meeting.

Stone, Alexander, and Weber at GSFC have performed further experiments to measure the impedance of an antenna in a rocket passing through the ionosphere, on a Javelin flight (NASA 8.44GR) to 918 km above Wallops Island on May 20, 1966. So far, only qualitative agreement has been obtained with theory. For observing-frequencies slightly less than the electron gyrofrequency, and near the plasma frequency, a large resistive component was noted. Above the electron gyrofrequency, large resistive components were found which correlated with apparent enhancements of received radio noise. The geomagnetic field produced large effects even when the observing frequency was much greater than the local plasma frequency.

Two Nike-Apache sounding rockets, instrumented by Haymes of Rice University, were flown during 1966 from Wallops Island to carry out measurements of the Sq current system. Each contained a cesium vapor magnetometer that was surrounded by a bias-coil system to provide vector information. The flights, timed to coincide with the maximum development of the Sq variation, detected currents in the ionosphere, and analysis is under way to determine the vector components of the currents.

Observations of neutral winds from visible TMA trails of gun-launched vehicles fired at Barbados in September 1965 were compared with simultaneous ground-based radio soundings of the ionospheric sporadic-E layers. The series of experiments was made by Wright of ITSA, Murphy of BRL, and Bull of McGill University and Stanford Research Institute. It was found that wind structure accounted for many features of the sporadic-E-layer variation on two nights of observation, through the vertical ion convergence induced by ion motion across the geomagnetic field. Sporadic E is found to accompany the height variation of levels of ion convergence indicated by the neutral wind. The peak electron density of the layers diminishes when the wind structure leads to ion divergence at the sporadic-E height, and the density is observed to increase when the ion velocity permits the descent of new ionization from above. New layers arrive at night in accord with the observed development and descent of new nodes of ion convergence. Together with other published evidence that similar layers consist of long-lived monatomic ions ultimately from meteoric influx, it was concluded that the neutral wind serves as a scavenger of this material which would otherwise accumulate to a far higher ionic concentration in the upper atmosphere.

Further spaced-receiver observations of ionospheric radio echoes by Wright and Fedor, performed during rocket and gun-launched vapor-trail experiments which reveal upper atmospheric wind profiles, showed that irregularities in the echo pattern drift across the ground. The results indicated that the radio experiment gives the correct wind direction at the level of radio reflection but that the speeds agree only if the classical radio reflection mechanism is reinterpreted.

The flux of low energy suprathermal electrons between 2 and 20 eV was measured as a function of energy and altitude on a Javelin flight (NASA 8.12UA) to 1015 km on July 12, 1966, by Donahue of the University of Pittsburgh. According to present calibration data the flux is much higher than expected for hot photoelectrons alone at all altitudes from 90 to 1000 km. It increases rapidly (much more rapidly than the electron density) through the E and F₁ regions and attains a maximum at the F₂ peak (which was at 250 km). Above the F₂ peak it decreases in a manner very roughly paralleling the expected electron density, with an average scale height of 100 km up to about 475 km, and a scale height of about 800 km above 550 km. At 250 km the 10-eV flux is of the order of 5×10^9 per cm² sec sr eV. The spectrum and altitude distribution is being analysed in terms of known cooling processes to determine if possible the source of this large flux, and the instrumentation is being analysed to establish the degree of reliability of the measurement. A similar measurement will be attempted in May 1967.

3. AERONOMICAL STUDIES WITH SATELLITES

Direct Measurements. The second NASA Atmosphere Explorer satellite, Explorer 32 (or AE-B; 1966-44A), was launched May 25, 1966. The primary objective of the Atmosphere Explorers is to obtain sufficiently accurate measurements of the upper atmosphere around the globe and its diurnal, annual, and other time variations to permit identification of underlying processes and an evaluation of their relative importance. The experiments and orbital parameters of Explorer 32 were selected to provide, with simultaneous operation, the basis for the study of physical processes as opposed to studies that are primarily mapping, descriptive, or of a survey nature. A second objective was to study the effects of short-term

perturbations of the atmosphere induced by the direct and delayed effects of solar storms. These effects will be primarily evident in the auroral regions and in the area of the South Atlantic magnetic anomaly. Explorer 32 was placed in an orbit with a higher apogee than planned; however, reprogramming of the experiments made all of them operable and the mission successful. Unlike Explorer 17, it carried a tape recorder for data storage. Four experiments, all from GSFC, were carried and returned data. Taylor built an ion mass spectrometer for the ions H^+ , He^+ , N^+ , and O^+ . Reber designed two mass spectrometers for the neutral atoms and molecules H , He , O , O_2 , N , and N_2 . Brace provided two electrostatic probes for measurement of the concentration and temperature of thermal electrons. The fourth experiment, by Newton, used three magnetron density-gauges for determination of neutral particle density and scale height. Both neutral spectrometers failed after 10 days of operation.

Data from the several thousand payload turn-ons, both in real time and from tape storage, are in the process of being reduced and analysed. A preliminary examination of some of the reduced data reveals: (1) In the altitude interval from 400 to 900 km, the change in the concentrations of N_2 and O due to a magnetic disturbance ($A_p=132$) was approximately three times larger in the atmosphere near the equator in early morning (0700 to 0800), than it was at high northern latitudes in the afternoon (1400 to 1800). During this disturbance, the neutral species did not react simply as if a temperature change had occurred in the region of diffusive equilibrium, but rather appeared to reflect changes in the boundary-level concentrations. A similar conclusion was drawn earlier based on Explorer 17 data. (2) From approximately 300 to 1000 km, the diurnal variation of the principal ions O^+ , N^+ , He^+ , and H^+ was measured, revealing a less pronounced variation for the lighter ions than for N^+ and O^+ . In the 1000-to-1500 km altitude region the ratio N^+/O^+ was approximately 0.1%. Near the apogee altitude, where the predominant population is He^+ and H^+ ions, the diurnal variation was quite small. (3) Unexpected variations appear to exist in the neutral density as a function of latitude. (4) Electron temperatures were approximately 30% higher during this period of increasing solar activity than those measured during solar minimum.

Satellite OV3-2 (1966-97A) was launched on October 28, 1966 into a polar orbit with a perigee 300 km and apogee 1590 km. In addition to ion mass-spectrometer and ion-trap data, measurements were obtained of electron density, temperature, and energy distribution using retarding potential analysers, electrostatic analysers, and rf probes. Of particular interest were the measurements coordinated with simultaneous ground measurements made over Ft. Churchill during periods of predicted auroral activity. A great deal of data has already been obtained and the satellite and all experiments on board still appear to be functioning properly. The data are in the process of being reduced and analysed.

The combined launching of Alouette 2 and Explorer 31 in November 1965 was intended to supplement topside-sounder data with direct-measurement experiments, and to determine whether direct measurements can be made on the same spacecraft that contains the large antennas necessary for the sounder. Although the analysis of comparative data is not complete, present indications are that such direct measurements can be accomplished, and that the steps taken to decouple the sounder antennas were successful in avoiding the generation of large local disturbances that would have made the incorporation of direct-measurement experiments on the same spacecraft worthless. The joint analysis of the data also leads to the conclusion that vertical gradients of electron temperature of the order of 1° to $2^\circ/\text{km}$ exist in the topside F region.

Data obtained by Lockheed from retarding potential analysers flown on two low-altitude,

polar-orbiting satellites (one in 1962 and one in late 1965) have been studied to give ion temperature as a function of latitude. Large and unexpected ion-temperature variations with latitude were observed. In addition to the fluctuations in and near the auroral zones, ion-temperature enhancements were found on either side of the equator near 1700 LT and 2300 LT at an altitude of 250 km. Measurements of molecular ion (O_2^+ and NO^+) and atomic ion (O^+) concentrations have provided data on variations of molecular ion concentration, and similar variations in total ion concentration, ion temperature and vehicle potential at 1700 LT and near 250 km altitude. Observation of the nighttime midlatitude ionospheric trough was made near 200 km and at 2300 LT. The trough was centered near $L = 4.5$, was broad in latitude, and relatively shallow in electron concentration, as one would expect for a time of low auroral activity.

Remote Sensing. The Solar-Atmospheric satellite OV1-10 (1966-111B) was launched December 11, 1966, into a near-polar, near-circular orbit at about 760-km altitude (Figure 6-1). The spacecraft is Earth-oriented by means of a gravity-gradient ("Vertistat") stabilizer, a stable platform for optical-type sensors pointing in predetermined directions in space. The following experiments were provided by the Aerospace Corporation: (1) Multicolor nightglow detector, down-looking, to scan over 6300, 5735, 5577, and 3914 Å, the intervals being defined by interference filters; (2) Solar-pointed x-ray detector consisting of a six-channel proportional counter for the range 0.5 to 14 Å, scanning crystal spectrometer for 7 to 25 Å, the whole directed by a biaxial pointer which seeks and holds the Sun centroid to less than 1 arc min; (3) Ultraviolet monochromator providing a downward-looking scan between 1600 and 3200 Å; and (4) Scanning Lyman-α detector providing a helical scan of Lyman-α about the direction of satellite motion. Other experiments aboard were a AFCRL heavy primary-cosmic-ray telescope and a magnetometer; a thermal control coating experiment by the Air Force Materials Laboratory; and a GSFC magnetospheric electric field detector. A similar payload is scheduled for launch in mid-1967 in OV1-11.

Drag Studies. A continuous record of upper-atmosphere densities throughout the years has been obtained at SAO through an analysis of the drag of six artificial satellites with perigees distributed between 250 and 650 km. Two of these satellites, Explorer 19 (1963-53A) and Explorer 24 (1964-76A), have yielded new information concerning density and temperature variations at high geographic latitudes. It appears that earlier models of the diurnal temperature variation require substantial modifications in the high-latitude regions to account for the new observations. A study of the upper-atmosphere heating that accompanies geomagnetic disturbances has shown that at low and moderate latitudes the atmospheric perturbation lags 7.2 hr behind the magnetic disturbance; above 55° latitude the lag is smaller, averaging only 5.8 hr.

An Air Density Explorer is scheduled for launch by NASA in late 1967 into a nearly polar, eccentric orbit with a perigee of about 480 km and an apogee of 4320 km. The spacecraft is a 4-m inflatable sphere of the same basic design as Explorers 9, 19, and 24, and will continue the measurements of the density of the upper atmosphere through changes in drag as shown by orbital changes. The Air Density Explorer is to be launched simultaneously with an Injun satellite carrying a payload of particles-and-fields experiments (see Chapter 5, Section 1).

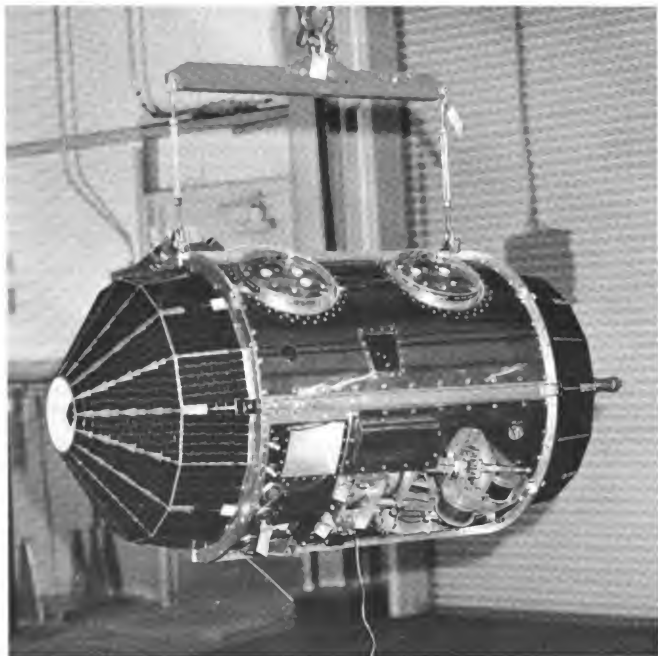


Figure 6-1. Solar-Atmospheric satellite OV1-10 (1966-111B) launched by the U.S. Air Force on December 11, 1966. ASD 614 sample holders are on top. Plastic covers are removed before flight (U.S. Air Force).

4. ATMOSPHERIC STRUCTURE STUDIES BY ROCKETS AND BALLOONS

Chemical Release Experiments. Two series of five Nike-Apache flights, utilizing both sodium and TMA vapor, were launched by NASA from Wallops Island on January 17-18 and on July 17, 1966. The experiments were conducted by Bedinger of GCA Corporation. In each series the five launches were made during a 24-hr period to obtain diurnal data for analyses of three postulated modes of motion in the upper atmosphere: internal gravity waves with a period of about 2 hr, atmospheric tidal motions, and the longer-term prevailing flow. The two series will permit the delineation of some of the seasonal aspects of these phenomena. Both series were entirely successful in obtaining the required data and analyses are under way.

A third series of five chemical release experiments conducted by Smith and Bedinger of GCA were flown on NASA Nike-Apaches from Ft. Churchill on September 14 and 16. Instrumented with Langmuir probes and ejecting sodium or TMA vapor, their primary objective was to compare the electron-density profile with the wind profile.

Chemical release experiments by AFCRL in 1966 included: (1) further studies of the relation between wind shear and sporadic E; (2) diffusion constant and temperature measurements in the 130-to-180 km region from AIO-resonance radiation; (3) total density and oxygen-atom measurements in the 90-to-140 km altitude region by NO release; (4) the measurement of atmospheric turbulence in the 30-to-80 km altitude region by Al_2O_3 smoke trails; and (5) the simultaneous measurement of radio reflections and (optical) density distribution and orientation of barium ion clouds by release of barium vapor. Results were as follows:

(1) Ionospheric winds measured in conjunction with the rocket-borne measurement of electron- and ion-density profiles have shown details of ionic composition to have a strong influence on the character of the neutral-ion-wind interaction. Further experiments in which vertical neutral winds have been measured indicate that the vertical wind may exert a controlling influence on the movement of lower E-region ionization.

(2) The fluorescent spectrum of aluminum oxide led to temperature estimates of the radiating molecules, which are assumed to be in thermal equilibrium with the ambient. On a summer evening during twilight at 30°N , $T=450^\circ\text{K}$ at 125 km, 650°K at 150 km, and 700°K at 165 km. From the growth of the trails, diffusion coefficients were deduced. In the evening twilight at 150 km, these coefficients are approximately twice as large as in the morning, being $4 \times 10^8 \text{cm}^2 \text{sec}^{-1}$ and $2 \times 10^8 \text{cm}^2 \text{sec}^{-1}$, respectively.

(3) Atomic oxygen concentration profiles in the 90-to-140 km region were obtained by analysing the radiation intensity of nitric oxide trails. Peak concentrations of 10^{11} atoms cm^{-3} occur between 103 and 107 km. The profile rises sharply from 90 km and decays more slowly above 110 km.

(4) Results of smoke trails in the 30-to-80 km region indicate that the wind structure in this region is more complex than could be inferred from soundings with falling-sphere or other techniques that tend to average out features with vertical scales of less than a kilometer; and that the radial growth rate at 40-to-50 km altitude is several hundred times that expected for molecular diffusion.

(5) The barium releases showed the field-aligned expansion and striations previously reported by the Max-Planck Institute investigators. For the first time, radio-frequency sounding showed a persistent echo from the ion cloud lasting for 2 hr at 190 km after release at sunset. Preliminary analysis of time-resolved spectra of the cloud suggests that the dominant initial ion-producing mechanism is the photoionization of metastable barium ions.

These are produced prior to pressure equilibration, i.e., either in the vaporization or expansion stages. During the first minute after release, the emission intensity of all the metastable lines, initially very intense, rapidly decreases to undetectable levels, while during the same period the ground-state emission tends to remain stable.

In cooperation with Project Harp and BRL, RIAS is developing a method for measuring the geoelectric field intensity at altitudes of 140 to 200 km. The technique under consideration involves the release of a quantity of barium at the given altitudes, some in the form of neutral atoms and some in the form of singly ionized barium. The neutral barium atoms will acquire the ambient wind velocity aloft; the ionized barium will undergo drift in the combined electric and magnetic fields of the Earth. Observations of the neutral and ionized clouds are to be made by photographic recordings of the resonant radiation produced at twilight by incident solar energy. The observed motion of the clouds together with the known geomagnetic field will permit a deduction of the electric field intensity (magnitude and direction) as well as of the wind velocity. Further development of the experimental techniques will permit a measurement of the barium atom and ion diffusion coefficients, temperature and pressure relations aloft, and the electron density. This experimental program is to be carried out in collaboration with project Harp using a sixteen-inch gun facility to achieve desired payload altitudes. Two such gun facilities are presently operational—one on the island of Barbados and one at Yuma, Arizona.

One of the most promising of the cloud-release techniques studied so far uses a chemical thermite composed of finely divided barium metal and copper oxide. Several canisters containing this mixture have been ignited by RIAS in ground tests to determine the parameters affecting their performance and to study details of the release process. Evidence thus far indicates that release packages containing about 300 g of this mixture will exhaust in 250 msec or less and reach internal temperatures high enough to vaporize a portion of the included barium. Packages of varying sizes and configurations are still under study, but a payload design suitable for gun launch is expected to be ready for first launching before the summer of 1967.

Solar Radiation Absorption Experiments. Six euv spectrophotometer flights, conducted by Hinteregger of AFCRL, were carried out on Aerobee rockets during the past year for the measurement of solar radiation in the wavelength range 230 to 1260 Å and at altitudes up to 245 km. These observations of solar euv absorption as a function of altitude were repeated over a period of time to provide a better understanding of the major role of the Sun's radiation in the formation of the ionosphere, the determination of upper atmospheric composition, and possible time-dependent variations therein. Each rocket payload carried a precisely calibrated telemetering monochromator, a retarding potential analyser for the determination of ion and electron densities, and a solar pointing control for accurate optical pointing of the instruments at the Sun during flight. Similar but more sophisticated AFCRL experiments were prepared for the OSO-E1 and the OGO-D satellites to be launched during 1967.

Three of the rockets (NASA 4.99DS through .101DS) were launched from Wallops Island on March 2 and 3, and August 26, 1966, respectively, in conjunction with other rocket and satellite observations of the vertical distribution of various parameters of the neutral upper atmosphere (see below, "Other Studies.") The other three AFCRL flights of scanning monochromators, from White Sands on March 30, July 22, 1966, and January 17, 1967 (AF 3.524 through 526), accomplished long-term monitoring of possible seasonal variations of solar euv-radiation intensities. Results of these observations, in addition to the Wallops Island flights and the five White Sands flights in 1965, are being evaluated to provide a better

understanding of time-dependent variations and their effects on the ionosphere and the upper atmosphere.

The fractions of the solar irradiance (0.25 to 14 μ) that are attenuated by absorption and by scattering in the atmosphere are being evaluated at AFCRL. The accumulated data on measurements of the solar constant are being reanalysed and programs are being developed for computing the path of a beam through the atmosphere and for calculating the optical air mass along the slant path as a function of wavelength. Pyrheliometers will be flown on balloons to refine the estimate of solar emission in the 0.25-to-3 μ spectral region. A study of the limits of accuracy of pyrheliometers is now under way.

Solar irradiation measurements using balloon-borne spectrographs at various levels in the atmosphere are being continued. In 1966, three balloon flights were made using a grating spectrometer and a biaxial pointing control and concentrated upon the ultraviolet spectral region from 2500 to 3500 Å. Two of these flights also sampled the 9.6 μ ozone band while the third unsuccessfully attempted to sample the 6.3 μ H₂O region. The data are being reduced and will be used to determine the distribution of ozone with altitude up to float altitudes reached by the balloons. The amount of ozone above these altitudes will also be determined on the basis of the absorptions observed at altitude. The comparison of predicted and observed transmittance in the 2.7 μ region for H₂O and CO₂ variations in the atmosphere is also continuing. Four more flights in the program are planned for 1967 to study the 8-to-22 μ , 3-to-4 μ and 1-to-2 μ regions. Equipment design has been completed, and the equipment is being readied for a series of eight flights, four daytime and four nighttime, the first to take place in early April 1967.

Three Black Brant rockets (NC7.181, .180, and .178) were launched by NRL on February 21, 1966 (one from Ft. Churchill and two from Eglin AFB) to investigate latitudinal and temporal variation of the turbopause, by determining the variation with altitude of O₂ and total particle density, measured in terms of absorption of solar uv and x-ray flux. Data on absorption of solar radiation of the Schumann-Runge continuum, hydrogen Lyman- α , and x-ray bands of 44 to 60 Å and 0 to 20 Å were obtained. The x-ray detectors also observed a background of particle flux. This experiment was conducted by Grobecker of NRL.

On October 11, 1966, the Kitt Peak National Observatory launched an Aerobee (KP3.16) from White Sands carrying an x-ray strip-film camera as one of its three instruments. Six wavelength bands in the range 8 to 50 Å were isolated with metallic and plastic filters to measure solar x-ray extinction as a function of altitude. A cross-spin stabilization system was used to reduce precession over apogee. (This system was also flown on NRL's NA3.160 on October 4, 1966.)

Two launches were conducted by NASA to further the development of instruments and techniques. An experimental instrument to measure solar uv energy in the spectral range 1200 to 3000 Å was tested successfully in September. This experiment is planned for inclusion in the Nimbus satellites. Three other experiments were flown on the same Aerobee 150 rocket which attained an altitude of 200 km. They were: measurement of day airglow in the far ultraviolet, the detection of molecular nitrogen in the 750-to-1000 Å band, and a Langmuir electron-temperature probe.

Other Studies. In an experiment conducted by Hoffman of NRL, a magnetic mass spectrometer on an Atlas rocket (NC 20.189), which was launched July 14, 1966, and attained an altitude of 1000 km, detected peaks of mass of 1, 4, 8, 14, 16, 18, 28, 30, and 32 amu. On August 15, Hoffman and Johnson carried out further investigations of atmospheric composition in a

Javelin flight (NASA 8.32DA) to 699 km above Wallops Island. Instrumentation consisted of (1) a magnetic mass spectrometer and two Bennett rf mass spectrometers to measure positive ion composition of the ionosphere and a planar trap to measure total ion density; (2) a probe to measure electron density and temperature; and (3) a Lyman- α experiment to determine the abundance of atomic hydrogen in the Earth's atmosphere by mapping the distribution of Lyman- α radiation.

To study diurnal changes in atmospheric composition and temperature, two Aerobee rockets (NASA 4.181UA and .180UA) each carrying three magnetic mass spectrometers, were flown at White Sands by Nier of the University of Minnesota on November 30 and December 2, 1966. Absolute concentrations of N_2 , O_2 , O, Ar, and He were measured in range 120 to 200 km and temperatures were determined from modulation of data as a result of the spin of rocket.

Several combined rocket shots took place in 1966 in an effort to measure simultaneously the neutral and ion density, composition, and temperature, and solar flux in the atmosphere as functions of altitude. Scientists from GSFC, the University of Michigan, and AFCRL collaborated in upper atmosphere, thermosphere, and solar radiation experiments. In one series, four rocket flights were launched in conjunction with an Explorer 32 pass over Wallops Island in the early afternoon of August 26, 1966. The first rocket was an Aerobee (NASA 4.101DS) instrumented by Hinteregger of AFCRL to measure incident euv solar radiation and its absorption in the upper atmosphere. Two Nike-Tomahawks (NASA 18.05GA and .06GA) carrying GSFC-University of Michigan thermosphere probes were then launched; one contained an omegatron spectrometer and a quadrupole spectrometer; the other contained an omegatron and an ion spectrometer. The rocket and satellite data showed good correlation. The fourth rocket, a Nike-Apache (NASA 14.285UM), carried a GSFC-Michigan pitot-static experiment to measure density and temperature to 100 km. In another combined shot on March 2-3, a NASA Argo D-4 geoprobe (NASA 8.25GA-GI) was fired in conjunction with two Hinteregger flights from Wallops Island. For these aeronomical studies, the conventional scanning monochromator had been modified to measure radiation intensities sequentially at nine significant wavelengths in the euv, permitting greatly improved altitude resolution, while retaining moderate wavelength resolution. Data from the March 2-3 flights are also being studied from the viewpoint of possible diurnal variations of the upper atmosphere.

Lockwood of the University of New Hampshire conducted a multiple experiment on November 30, 1966, on NASA 18.27UE from Wallops Island, to provide data on (1) neutron intensity utilizing a neutron detector; (2) solar x-ray fluxes using an x-ray counter 2 to 10 $\text{\AA}$; (3) Lyman- α radiation using a photolionization chamber to measure 1400-to-1200 $\text{\AA}$ solar radiation; and (4) Faraday-rotation experiment using a 1- and 3-MHz receiver, and ionospheric electron-density measurements. The data obtained on the various sensors appear excellent. The x-ray detector viewing the Sun saw large counting rates, which saturated the detector.

The AFCRL program to measure the infrared radiance (limb darkening) of the atmosphere near the horizon (limb) was continued in 1966. Aerobee 150's were instrumented with radiometers programmed to scan up and down across the horizon while the rocket was stabilized in attitude and slowly rotated in azimuth. Two flights (AD3.723 and .724), conducted by Cunniff, were made during 1966 at White Sands on April 29, and December 6. The April launch obtained data in the spectral regions 19 to 30 μ , 10.2 to 11.8 μ and 15 μ , while the December flight measured horizon radiance in the 9.6 μ , 10.2-to-11.8 μ , and 15 μ regions. Photomultipliers with coded reticles were used to obtain star positions relative to the rocket and thus determine more accurately where the radiometer was pointing. Both flights were successful and the data are currently being reduced. One more rocket flight with this type of instrument will be flown

from Ft. Churchill, while two follow-on flights with more sophisticated instrumentation will also be launched from Ft. Churchill for infrared horizon determinations accurate to 1 arc min.

The bremsstrahlung emitted by high speed electrons as they are slowed down by collisions with atoms and molecules can be detected and used to measure atmospheric density. A rocket payload incorporating two electron guns and two radiation detectors is being developed by McIsaac at AFCRL to apply the bremsstrahlung principle. One test flight (AF7.327) was made at Eglin on March 10, 1966. All components of the payload operated satisfactorily except one of a set of three doors. Useful background information was obtained.

In a balloon flight over Palestine, Texas in May 1966, Chaney of the University of Michigan made measurements of atmospheric thermal radiation in the 5-to-18 μ region. The resolution was 5 cm^{-1} with errors not exceeding 0.5% of full scale. The 11-to-20 μ region of the spectrum was measured vertically downward through clear skies at 0730 CST from 33.5-km altitude. Upward radiation was calculated from temperatures measured by radiosonde at about the same time. CO_2 transmissivities, which resulted from the extensive study of the 15- μ CO_2 band at Michigan, were used in the calculations of results. The theoretical and experimental data are in excellent agreement for almost all of the CO_2 band. They depart from one another at about 16.7 μcm^{-1} , because of the effect of water vapor, which was not considered in the theoretical calculation.

The University of Minnesota, in conjunction with the ONR Skyhook program, conducted eight balloon flights in 1966 in the Minnesota area using dust detectors to count particles of 0.25 μ in diameter and larger in combination with chemiluminescent-type ozone detectors. Two similar flights were made from Ft. Churchill. Arrangements were also made to conduct two balloon flights in Panama to determine vertical distribution of dust and to measure light extinction.

The BRL program for development of gun-launched atmospheric probes (Project Harp) was continued in 1966. Several series of firings were conducted at Yuma Proving Ground, Arizona. A total of 21 five-inch rounds carrying parachutes for wind measurements were fired in June, October, and November; 29 sixteen-inch TMA rounds were fired in October and November. Thirteen of the November shots were dual firings in which a five-inch round followed 3 min after a sixteen-inch round. On November 19, 1966, a new altitude record of 180 km was achieved for the sixteen-inch gun. Estimated muzzle velocity was 2160 m/sec. A total of 61 five-inch rounds was fired at Barbados, including 50 parachute and 4 chaff rounds for wind measurements, 6 parachute-borne temperature sensors, and a vehicle-test round. A total of 36 sixteen-inch rounds were fired in February, August, September, and October, including 19 successful TMA rounds, 3 successful Langmuir probes, and various engineering tests.

5. AIRGLOW

Gemini 9, launched on June 3, 1966, contained a 50-mm $f/0.95$ camera equipped by NRL with an illuminated sight, window mount, and several filter combinations for photography of the night-airglow horizon. Filters allowed photography in two narrow bands centered on the line emissions, O II 5577 $\text{\AA}$ and Na I 5893 $\text{\AA}$. Other filters included an orange glass, which recorded wavelengths 5890 $\text{\AA}$ and longer, and didymium glass which recorded essentially the

visible spectrum excluding a band centered at $5893 \text{ \AA}$. Astronauts Thomas Stafford and Eugene Cernan obtained 44 good photographs of the horizon airglow layer at various azimuths and geographical locations which can be analysed to obtain airglow intensities and altitudes. Camera pointing was satisfactorily maintained for exposure times as long as 20 sec.

A continuing program of Lyman- α glow observations by NRL is incorporated in the NASA Orbiting Geophysical (OGO) and Orbiting Solar (OSO) Observatory programs. Specifically, Lyman- α experiments were launched into orbits with apogees as great as $23 R_e$ on OGO-1 (September 5, 1964) and OGO-3 (June 7, 1966), and into a low polar orbit on OGO-2 (October 14, 1965). Experiments are also planned for OGO-D and OSO-E to be launched in 1967. Many of the data from the first two OGO satellites are compromised by lack of vehicle attitude information or control; however, spot checks of OGO-1 results during the spring of 1965 and 1966 have shown that the Lyman- α intensity in the general vicinity of right ascension 44° , declination -14° , falls by a factor of 7 in an irregular way as the satellite moves along its orbit from an altitude of <1 to $23 R_e$. Early data from OGO-3 in its planned attitude, which provides a view outward from the Earth for the Lyman- α experiment, have exhibited a smooth increase in intensity on approach to perigee, and a remarkably constant intensity through successive apogees. Eclipse effects are clear-cut as perigee is approached. Systematic review of all data from OGO-1 and 3 is now under way.

Although only a limited number of ideal data can be obtained from the OGO-2 satellite, several interesting and unusual features have been observed in the preliminary analysis. For example, on two successive passes just less than 2 hr apart, the Lyman- α glow was observed under eclipse conditions. During the first pass Lyman- α intensities from zenith and nadir (at about 430-km altitude) were roughly equivalent, whereas on the second pass the glow from space had increased by some 80%, although the glow from the Earth had not changed markedly. Of course, this must be interpreted carefully after a review of data taken in OGO-2 under all similar observational conditions. It is now clear that the Lyman- α data obtained from the OGO program constitute a unique collection of data never available before, from which further insight into the nature of the hydrogen geocorona should be derived.

NRL has also provided Lyman- α photometers which were carried in scientific passenger pods on Atlas vehicles used as boosters for Air Force research-satellite launches. After powered missile flight the pods were ejected from the booster vehicles into independent nighttime trajectories which began after midnight and "pursued the setting Sun" across the Pacific Ocean on October 5, 1965 and March 30, 1966. Interpretation of the results in terms of specific hydrogen models is not yet accomplished, but the data show a smooth variation as a function of altitude and longitude throughout the flights which implies a stable distribution of the scattering medium during the dark hours.

A spectrograph using image converter tubes for photographing the ultraviolet airglow at high dispersion is essentially completed at NRL and scheduled for launching in an Aerobee rocket early in 1967. A visible airglow horizon camera and an ultraviolet star-field camera, each using an image converter tube, will accompany the spectrograph.

The University of Colorado's scanning uv spectrometer aboard OGO-2 that has been in operation since the fall of 1965 has continued to map the intensity of the hydrogen Lyman- α dayglow surrounding the Earth.

A Lyman- α detector was flown on OV1-10 by Clark and Metzger of the Aerospace Corporation. Depending on the degree of stabilization, the instrument executed a helical scan about the direction of the satellite motion. Initial data reveal zenith and nadir intensities much higher during the day than at night at 700 km (>10 to 1). The relative zenith/nadir intensities (~ 1.2) suggest

that more hydrogen is present above this altitude (~ 760 km) than was previously expected. The nighttime latitude distribution is fairly flat, with a zenith intensity about 300 rayleighs (R). The instrument includes both molecular oxygen and atomic hydrogen filters.

He 584 Å dayglow brightness was measured by University of Pittsburgh scientists in a Javelin flight (NASA 8.12UA) on July 12, 1966, from Wallops Island. Data were obtained on the upleg from 350 km to 1016 km and on the downleg to 93 km. The maximum zenith emission rate observed was 2 kR near 400 km. The helium distribution from 200 km to 1000 km required to produce the 584 Å line by resonance scattering is not in diffusive equilibrium. The distribution suggests an upward flow of the order of 2×10^6 atoms/cm² sec. Hydrogen Lyman- α dayglow was also observed. The emission rate was 13 kR. The appropriate hydrogen distribution is consistent with that expected for the prevailing exospheric temperature and 3×10^7 atoms/cm³ at 100 km.

An Aerobee 150 (NASA 4.156GM) was launched from White Sands on August 29, 1966, in an experiment conducted by Heath of GSFC to (1) measure solar-uv energy in the range 1200 to 3000 Å, (2) look for polarization of dayglow in the far uv (1200 to 2000 Å), (3) detect emission from singlet systems of N₂ in the far uv (750 to 1000 Å) in dayglow, and (4) measure the electron temperature and density in dayglow. The polarization of the dayglow was detected in the far uv; the N₂ photometer saturated for most of the flight; the other experiments functioned well.

Aerospace Corporation scientists flew downward-looking nightglow and dayglow detectors on satellite OV1-10. Elliott and LaValle observed the nightglow through four narrow-band filters at 6300, 5735, 5577, and 3914 Å, with an associated Geiger tube to detect energetic particle fluxes. The full latitude distribution of the nightglow, from northern to southern terminators, was measured in 30 min at a constant local time of 0100 along the track. Preliminary results show a relatively constant 3914 Å glow of magnitude 10 R from a typical orbit. The 5577 Å emission showed a minimum (~ 150 R) at the magnetic equator, a maximum (~ 500 R) at midlatitudes, and was approximately symmetrical in the Northern and Southern Hemispheres. Outside the auroral region, the auroral variations in the 5577 Å intensity are not correlated with the Geiger tube outputs. At 6300 Å the distribution was nearly constant at about 30 R, except for a 150-R peak at 10°S; this peak was about 7° wide. No northern peak was observed. Barbier's tropical red arcs do not appear to be permanent features of the 6300 Å nightglow. The continuum at 5735 Å was fairly constant at 1 R/Å. Several bright northern auroras were seen with these detectors over a period of two months. The largest was a class 3 (100 kR at 5577 Å) on February 14, 1967. The latitude extents of these auroras were unexpectedly large, 15°. The structure in the three wavelengths, 3914, 5577, and 6300 Å, and the structure in the Geiger-tube counting rates (electrons > 40 keV and protons > 700 keV), are well correlated, thus supporting the earlier findings of Van Allen and O'Brien.

The dayglow instrument, flown on the same satellite by Hudson, Elliott, Clark, and Chater, executed a 20-sec scan (corresponding to 1.3° latitude change) between 1600 and 3200 Å, at a bandwidth of 6 Å. The radiance intensities are in general agreement with those calculated under the assumptions that the only pertinent processes are Rayleigh scattering and ozone dissociation. The Schumann-Runge bands of O₂ and the uv bands of NO are not discernible. A follow-on flight in early summer 1967 will be carried out at 1.6 Å resolution, in a further attempt to see these bands. The present data are being analysed to yield the daytime ozone profile above 25 km as a function of latitude from about 75°N to 60°S along a meridian at 0100 LT.

Packer and Gullede of NRL have reported a high-level OI green-line 5577 Å airglow layer observed coincident with the red 6300 Å radiation in a layer about 50-km thick and peaking

near 245 km. This was observed from an Aerobee rocket (ND 3.167) carrying liquid-nitrogen-cooled photometers and launched at nighttime from White Sands on October 23, 1965. The green intensity was 10% of that in the lower layer near 100 km. The ratio of emission rates for the red and green radiation was about 3, which suggests that dissociative recombination is responsible for these emissions. The results are also consistent with the ground observations and ionograms made before, during, and after the rocket flight.

University of Pittsburgh workers have conducted joint photometric experiments with Johns Hopkins University using Aerobees in February 1966 (NASA 4.162UA) and February 1967 at Ft. Churchill to measure the height distribution of excitation of spectral features of auroras. Results obtained in a February 1965 flight by Johns Hopkins and Los Alamos have also been analysed. The results show clearly that the N_2^+ First Negative (O-O) band at 3914 Å and OI 5577 Å are excited predominantly from 5 to 10 km below all other emissions studied—OI 1302-06 Å, OI 7774 Å, OI 8446 Å, N_2 First Positive Group and O_2^+ First Negative. All OI 6300 Å emission occurs at very high altitude (above 160 km). It was concluded that the 3914 Å band of N_2^+ is excited for the most part by a process involving slow electrons (~3 eV) and not directly from the ground state of N_2 . A process involving vibrational excitation of N_2 by slow electrons and subsequent excitation transfer to N_2^+ is suggested.

On October 11, 1966, Kitt Peak National Observatory launched an Aerobee (KP 3.16) from White Sands at 2322 UT to observe the dayglow. An Ebert-Fastie spectrometer was used in the wavelength range 7300 to 11,500 Å. Sufficient intensity was observed in the 7620 Å and 8645 Å bands of O_2 to yield approximate altitude profiles. The 9145 Å band of N_2^+ as well as the 7774 Å and 8446 Å lines of atomic oxygen were also observed. In a cooperative experiment with the University of Saskatchewan, two filter photometers viewing the O_2 bands at 7600 Å and 12,700 Å observed strong emission upward of 40 km. The 12,700 Å band is the strongest emission to be found in the dayglow ($\sim 2 \times 10^7$ R). An x-ray extinction experiment was also carried on this flight.

Good altitude profiles of the sodium dayglow have been derived from data obtained on KPNO Aerobee flights in April and June 1964. A daylight enhancement of 45% was found in April but not in June. The top of the day layer had the remarkably small scale height of 3 km, differing considerably from that predicted by photochemical theory (7 to 8 km). The June flight also carried a lithium photometer which was unable to detect any lithium emission.

The results of the previous AFCRL rocket flight from White Sands, designed for day airglow measurements, were analysed to give the day skylight intensity from 20 to 90 km. The absolute intensity of the diffuse day skylight in the zenith was measured with rocket-borne instrumentation. The measurements showed good consistency with independent measurements at sea level and above 90 km. A simple Rayleigh scattering model of the upper atmosphere explains the exponential variation of intensity with height. The intensity variation yields a scale height of 6.3 km for the height range 20 to 90 km.

At the University of Alaska's Geophysical Institute, data on uv radiation from the aurora obtained from rockets launched in previous years from Ft. Churchill are being analysed by Murcray. This analysis is proving quite productive since it is putting emphasis on points that had previously been doubtful or not considered. In particular, the spatial distribution of OI and N_2^+ auroral light in a horizontal plane is not the same; furthermore the ratio of intensities [$I(5577)/I(4278)$] does not change over an altitude range where the OI/ N_2 ratio changes by a factor of 10. These two facts seem to show definitely that 5577 Å is not excited as a straightforward result of the primary electron bombardment and the associated secondaries.

Meteorology

1. METEOROLOGICAL STUDIES WITH SATELLITES

Nimbus Satellites. The overall objective of the Nimbus program is to develop and learn to apply space technology to meteorological purposes. The Nimbus 2 (1966-40A) satellite has obtained almost continuous, regular global observations of meteorological features on four different size scales and in seven spectral bands, with three basic experimental sensory systems: (1) an array of television cameras consisting of the Advanced Vidicon Camera System (AVCS) and the Automatic Picture Transmission (APT) camera; (2) a scanning High-Resolution Infrared Radiometer (HRIR); and (3) a scanning, five-channel Medium-Resolution Infrared Radiometer (MRIR). The AVCS, HRIR, MRIR data were stored on tape recorders in the spacecraft and read out whenever the satellite was within range of the prime data-acquisition facilities at Rosman, North Carolina, and Gilmore Creek, Fairbanks, Alaska. The APT television pictures transmitted directly to any of the APT ground stations throughout the world afforded meteorologists of many countries an inexpensive way to participate and benefit from the advances of satellite meteorology. An innovation on Nimbus 2 was the transmission in real time of the nighttime HRIR data to world-wide users, augmenting the daytime APT pictures with nighttime infrared cloud-mapping pictures.

Nimbus 2 was launched from the Western Test Range, California, on May 15, 1966, into a nearly polar, circular, Sun-synchronous orbit. Stabilization of the spacecraft in three axes permitted continuous Earth-orientation of the meteorological sensors, generally within $\pm 1^\circ$. All experiments have performed as planned. After almost 8 months in orbit the APT system is still operating and transmitting pictures to more than 162 independently operated APT ground stations throughout the world. Due to tape-recorder malfunctions the MRIR, AVCS, and HRIR systems ceased their transmission on July 29, August 31, and November 15, 1966, respectively. Nevertheless the Nimbus 2 satellite has provided the most complete continuous global meteorological observations to date and, by means of the MRIR system, the best satellite observations yet of the vertical structure of the lower atmosphere. Basically, the MRIR measurements are of the same nature as those obtained previously on four Tiros satellites. The spatial resolution is also very similar to Tiros, but accuracy, data coverage, and data reduction have been

greatly improved in the Nimbus 2 experiment. Also, scanning across the surface of the Earth was performed by a mirror rotating similarly to that in the HRIR instrument, which results in a much simplified scanning geometry. This was not possible with the spinning Tiros spacecraft. It permits the data for all five channels to be displayed automatically on a photographic time-strip chart with appropriate geographic referencing immediately after transmission from the spacecraft. Figure 7-1 provides an example of the data obtained in the five spectral regions with the MRIR. On the MRIR strip chart intense cloud bands can be seen in the infrared channels just north of the equator. The grey scale calibration associated with the window channel indicates 200 to 210° K as the temperature of the highest cloud tops. This and the fact that the cloud formation is highlighted in the water-vapor channel suggest that the cloud tops rise into the upper part of the troposphere. This cloud system is associated with the intertropical convergence zone. At 30°S, the window, water-vapor, and other ir channels indicate a major cloud system. The boundaries between cold (moist) and warm (dry) regions aloft associated with the cloud systems are well pronounced in the water-vapor channel. These inferred, synoptic-scale contrasts in moisture content have permitted a better insight into the circulations overlying fronts, storms, and other cloud formations than would be possible with the window channel alone. Frequently these sharp moisture boundaries occur in areas where the window channel does not show a clear differentiation between cloudy and cloud-free areas. The data contained in this strip-chart pictorial display were used experimentally for immediate meteorological interpretation of cloud patterns and cloud heights.

Complete quantitative interpretation of the Nimbus 2 measurements must await computer processing of all the data, i.e., high resolution temperature measurements of water, cloud, and land surfaces at night with the HRIR; determination of surface emissivities at 4μ from daytime HRIR observations; derivation of atmospheric water-vapor content; and the variations in the balance between emitted and absorbed radiation that will be available for the first time in the polar regions. Some preliminary measurements have been reduced manually. They resulted in the determination that the absolute calibration of the MRIR, especially for reflected radiation, has been much more stable during operation in orbit than in the case of similar radiometers on Tiros. Over thick (bright) clouds, reflectances of 0.60 to 0.70 were measured in the 0.2-to-4.0 μ channel. Over low-level stratus clouds off the coast of California, reflectances were 0.42 to 0.53 and over the Sahara desert they averaged 0.30 to 0.34. Total reflected solar and emitted terrestrial radiation measured by Nimbus 2 on a global scale during the first 2 weeks in July show the same latitudinal variation predicted by theory and measured by Tiros. Minimum total outgoing radiation is less than 0.2 langley (ly) per min at the South Pole and the maximum is about 0.37 ly/min near 15°S. The global average for total outgoing radiation for this time period is 0.32 ly/min. Inferred global albedos, however, are much less required by theory. This discrepancy has not yet been resolved. The global average inferred from Nimbus 2 for the first 2 weeks in July 1966 is 23% as compared with an expected value of 30 to 35%; the maximum of 45% occurs at the North Pole and the minimum of 15% occurs at 20°S.

Reflectances between 3.4 and 4.2 μ measured by the HRIR in daytime were 0.25 over the Sahara desert and less than 0.10 over oceans and the Great Lakes. The HRIR also measured ocean temperatures off the coast of North Carolina. Temperatures ranged from 287° K in the coastal waters to 294° K over the open Atlantic. A sharp temperature gradient marks a warm band extending from Cape Hatteras in a northeasterly direction across the Atlantic. This warm band obviously traces the course of the Gulf Stream. Sea temperatures of 286° K were also measured in the MRIR window off the coast of San Francisco, California, on June 13, 1966. Temperatures of 288° K were obtained in simultaneous aircraft measurements over the same area.

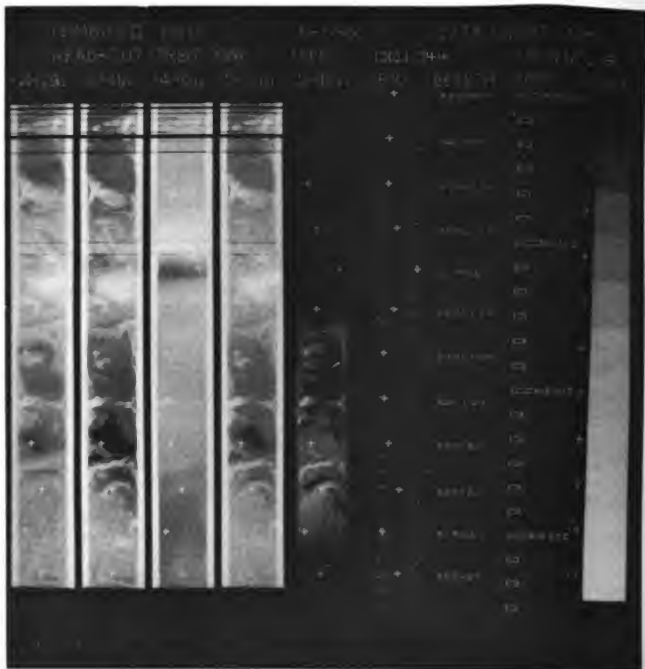


Figure 7-1. Computer photograph of Nimbus 2 multispectral imaging in which all five channels are displayed automatically on a time-strip chart with geographic referencing. The five channels are: (1) Water vapor absorption band, 6.5 to 7.0 μ , (2) Atmospheric window, 10 to 11 μ , (3) Stratospheric temperatures, 14 to 16 μ , (4) Terrestrial radiation, 5 to 30 μ , and (5) Albedo, 0.2 to 4 μ (NASA).

The Nimbus 2 television cameras and HRIR aided ESSA in the detection and tracking of 17 typhoons and 9 hurricanes during the 1966 tropical storm season.

A unique feature of the Nimbus satellite program is its automated data-cataloging and retrieval system, developed and employed successfully with the Nimbus 2 data. The computerized data system permits users to order pictorial data by the categories of meteorological phenomenon, geographic location, type of data, orbit number, sensor, or any combination of these, through the availability of five volumes of the Nimbus 2 Data Catalogs. The meteorological and geophysical classification scheme provides a standard means of classifying the cloud and land features observed in meteorological photographs and photofacsimiles. A four-level, logic-tree classification system is utilized which allows relatively objective and descriptive identification of major cloud (such as vortices and frontal bands) and land features, and subjective interpretation of mesoscale cloud patterns and small scale terrestrial features. Also of special value to the users of Nimbus 2 data will be the publication in early 1967 of pictorial catalogs containing AVCS, HRIR, and MRIR data. The AVCS and HRIR 70-mm strips are presented in world-montage format, with the MRIR 8×10 in. pictorial display shown for each orbit. A complete pictorial display of satellite-data accumulation and a means for data identification, classification, and retrieval will thus be available.

Another Nimbus satellite is scheduled for launch in winter 1967-68 thus extending the capability for quantitative measurement of atmospheric structure on a global scale. Experiments include an ir interferometer, an ir spectrometer, and a solar-uv experiment. The eight-channel infrared spectrometer is being constructed at ESSA's National Environmental Satellite Center. It will provide data from which will be inferred the atmospheric vertical temperature profile. One measurement in the $11.1\text{-}\mu$ region and seven in the 12- to $14\text{-}\mu$ CO_2 band will permit inversion of the radiative transfer equation to yield the temperature profile. Solutions are being developed for clear, partly cloudy, overcast and/or high, thin cloud conditions. In support of the ir spectrometer experiments, ESSA laboratory measurements of the absorption spectra of H_2O and CO_2 are being performed using a high-resolution spectrophotometer.

The Nimbus spacecraft will also carry an Interrogation, Recording and Location Subsystem (IRLS) to collect meteorological data on a global scale from remote sensors on balloons, ocean buoys, and remote weather stations; a high-resolution (HRIR) and a five-channel medium-resolution (MRIR) infrared radiometer; and an image-dissector camera system with provision for readout of the data to local users through their APT ground stations.

Tiros Satellites and the Tiros Operational Satellite (TOS) System. The TOS system, which is the first component of the national operational meteorological satellite system, has provided global cloud observations twice daily since its initiation in February 1966. ESSA 1 (1966-8A), the first Environmental Survey Satellite in the TOS system, was launched February 3, 1966, into a near-polar, Sun-synchronous orbit. It carried two 1.3-cm vidicon cameras identical to the ones used on the Tiros satellites. The orbital altitude of 764 km required the operation of both cameras for complete global coverage. The satellite takes pictures during the daylight portion of each orbit, stores the pictures on magnetic tape, and then transmits the stored pictures to ESSA ground stations near Fairbanks, Alaska, and at Wallops Station, Virginia. The picture data are then relayed via ground-communication links from the ground stations to the National Environmental Satellite Center, Suitland, Maryland, where the data are processed, furnished to the National Meteorological Center for use in operational weather analyses and disseminated world-wide. The failure of one camera on ESSA-1 in July 1966 resulted in the loss of complete global coverage by this satellite. Nimbus 2 and Tiros 9 were programmed

to provide the additional data required for global coverage until a replacement satellite could be launched.

ESSA-2 (1966-16A), the second satellite in the TOS system, was launched successfully on February 28, 1966, into a nearly polar orbit at an altitude of about 1400 km. Two APT cameras provide direct readout pictures in daylight to the 162 APT ground stations around the world. The cameras are operating satisfactorily after 11 months and are programmed daily to provide information on existing weather conditions over a large area around the local APT stations. In October 1966, ESSA-2 entered a morning-twilight period blanking out APT photographic coverage of the top portion of the Northern Hemisphere. The Nimbus 2 APT camera was programmed to provide cloud-cover data for this area of the globe until ESSA-4 was launched in January 1967.

ESSA-3 (1966-87A) was launched on October 2, 1966, to replace ESSA-1, into a nearly polar, Sun-synchronous orbit at a height of approximately 1400 km. It was the first ESSA spacecraft to carry the Advanced Vidicon Camera System (AVCS) developed for and successfully flown on Nimbus 1 and 2. The orbital altitude of 1400 km allows full global coverage with one camera; therefore, two cameras provide full system redundancy. The cameras are providing excellent quality pictures, and Figure 7-2 is a photomosaic of the global cloud cover on October 31, 1966, prepared from the ESSA-3 photographs. Of particular note are the extensive cloudiness and storms in the high latitudes of the Southern Hemisphere. ESSA-3 is also the first Tiros Operational Satellite (TOS) to carry an ir radiation monitor. These low-resolution sensors were designed to provide global measurements of the solar radiation reflected by the Earth and its atmosphere and the emitted long-wave radiation of the Earth. This instrument was designed and built for ESSA by the University of Wisconsin. The ir data are being used to assist in charting the heat balance of the Earth.

ESSA-4 (1967-6A) was launched on January 26, 1967, to continue the direct readout APT capability providing real-time cloud photographs to anyone who wishes to receive them.

Among advances in application of satellite data is a computer-produced "digitized" mosaic, produced daily, in which the original analog signal is converted to digital information which is then gridded, rectified to any desired map projection and scale, and the individual pictures combined into a hemispheric mosaic. Wind analyses at 200 mb in the tropics, derived from cirrus configuration, are supplied daily to the National Meteorological Center. Several analysis-correction schemes using satellite photographs are in use, and for Southern Hemisphere analysis the satellite photographs are the principal source of data. TOS data continue to be a principal source for the detection and surveillance of tropical storms and other hazardous large-scale weather systems.

The initial Tiros Operational Satellite system requires two satellites in orbit to fulfill the minimum requirements of direct readout of cloud-picture data during daylight (APT), and accumulating daytime cloud-cover pictures over the entire Earth once each day by transmission to the ESSA readout stations. The TOS Improvement Program was reoriented during 1966 to concentrate on the ultimate goal of having a single spacecraft perform the total requirement for local and global imaging both day and night. Such a spacecraft (designated Tiros-M) was designed and long-lead-time hardware developments were initiated during 1966. This spacecraft will be Earth-oriented by a gyromagnetic stabilization system and will have increased power and sensory capability over the current TOS spacecraft. The sensors planned for Tiros-M include (1) redundant APT and AVCS camera systems for local and global daytime cloud observations, and (2) the HRIR system with provisions for direct readout of data to the APT ground stations, thus providing both local and global nighttime cloud data. Tiros-M will be the



Figure 7-2. ESSA-3 24-hr cloud cover, October 31, 1966 (NASA).

experimental prototype of the second generation of TOS spacecraft (Improved TOS). The launch of Tiros-M into an orbit similar to the present TOS is planned in late 1968.

The TOS Improvement Program also includes the development of a vidicon camera with significantly higher resolution than is now available and the improvement in quality, reliability, and yield rate of vidicons presently used in the meteorological satellite program. NASA is also developing a system to include geographical reference data in the satellite so that the APT photographs transmitted to readout stations would include grid lines or positions. This system would eliminate the manual methods presently employed with each APT photograph to determine geographical location. It would also eliminate the need for furnishing a fairly large amount of orbital data to the network of APT users.

ESSA routinely uses satellite pictures in conjunction with conventional observations in preparing weather analyses and forecasts. In addition, research with satellite pictures includes the development of methods for operational applications of satellite data, the development of means for deriving quantitative values from the satellite photographs for direct input to mathematical models for use in numerical weather prediction, and the study and interpretation of synoptic and mesoscale cloud patterns depicted in the satellite pictures. The areas of investigation are diverse and include supplementary conventional data for studying jet streams, cyclone developments, mesoscale clouds, and hurricane and typhoon formations.

ATS Meteorological Flight Experiments. The Applications Technology Satellite (ATS-1; 1966-110A) launched on December 6, 1966, into geostationary orbit (35,700 km), carries a spin-scan camera experiment that can provide cloud pictures of the visible hemisphere of the Earth about every 20 min. The camera has been providing pictures of excellent quality with a ground resolution of about 4 km. Figure 7-3 shows a sequence of 34 pictures taken on December 11, 1966, which provided coverage of the hemisphere centered at about 160°W throughout that day. This sequence of pictures demonstrates the capability of synchronous satellites for nearly continuous observation of the Earth's clouds. The spin-scan camera pictures will be useful for detecting and tracking short-lived weather phenomena, for observing the motion of hurricanes and typhoons, and for identifying rapid weather changes associated with storms and frontal systems. With ATS-1 located at 151°W , the area coverage extends from the west coast of South America to mid-Australia, and from the southern tip of South America to the Aleutian Islands. The satellite's spin motion provides the west-to-east scan. A precision latitude-stepping device tilts the camera each time the spacecraft makes a revolution and provides the north-to-south scan. Normally, the camera returns to the north-latitude position at the conclusion of each picture; however, it can be programmed to scan selected north-south areas of the Earth thus permitting more frequent observations of specific cloud systems.

A Weather Facsimile (WEFAX) experiment is also being conducted using the VHF-communications system on ATS-1. Its major objective is to demonstrate the feasibility of disseminating meteorological data from a central weather station to widely scattered remote APT stations. The weather charts being transmitted consist initially of current weather analyses and forecasts prepared by ESSA. Also selected cloud photographs from the spin-scan camera are transmitted via the ATS-1 VHF transponder to the APT ground receiving stations. The WEFAX experiment has been conducted for 1 to 2 hr daily since December 21. To date, 48 APT users have participated in the experiment including stations in four foreign nations. Most of the participants have indicated that the WEFAX transmissions are of good quality and that this additional information is useful in their weather analysis and forecasting.

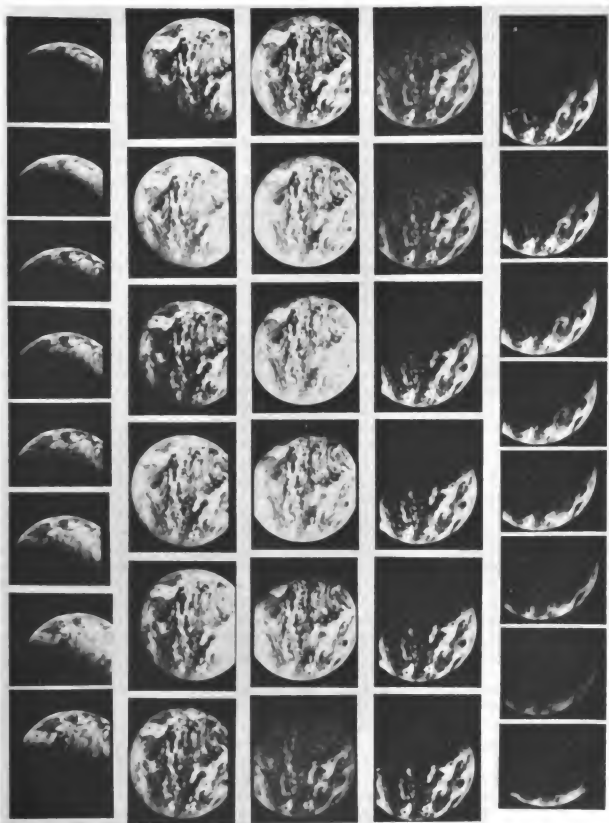


Figure 7-3. ATS-1 Spin-scan camera 18-hr cloud-cover sequence, made on December 11, 1966 (NASA).

Optical Measurements Satellite. The OV1-5 Optical Measurements satellite (1966-25B) was launched by the Air Force on March 30, 1966, into a low-inclination retrograde orbit with an apogee of 1054 km and a perigee of 980 km. The satellite's radiometric and interferometric optical systems, measuring in the spectral region from 0.25 to 30 μ , have obtained data on Earth and water backgrounds, the horizon ozone region and cloud formations. Background measurements made on OV1-5 compare very favorably with data collected on Gemini 5 and 7 by AFCRL in the same spectral regions using similar instruments with the same fields in view, filter bandwidths, and resolution. Optical measurements have been made for specific desert and mountain terrain over Australia, Africa, and parts of Asia and extensive measurements have been made in the vicinity of Cape Kennedy and in the downrange stations of Antigua and Ascension Island. A considerable number of orbits have been coordinated with Tiros flights to allow a much more meaningful reduction, correlation, and analysis of data for specific cloud types and weather conditions. Although some spectral and radiometric data have been collected over the entire satellite orbit, measurements have been concentrated over certain areas such as Cape Kennedy. In these areas data were collected on both day and night passes for at least one week, and in some cases for two weeks.

A first review of the data indicates that excellent results have been obtained by both the spectral and radiometric systems. Good data have been collected in the atmospheric windows at 1.5 and 2.2 μ , the absorption bands at 2.7 μ , the atmospheric window from 8 to 12 μ , and the ozone region 0.25 to 30 μ . The instrumentation, detectors, spectral regions covered, pointing directions, and optical targets included: (1) an interferometer with PbS/bolometer detectors, nadir-pointed to cloud, land-formation, and ocean targets, which obtained data in the 1-to-12 μ spectral region; (2) a radiometer with a PbS detector pointing to the nadir at the same targets in the 2.2 and 2.7 μ region; (3) an AC radiometer with PbS detector, nadir-pointed toward clouds, oceans, and cities to obtain 50-to-5000 Hz data; (4) a radiometer with PbS/photomultiplier/bolometer detectors, horizon-pointed at clouds, land formations, oceans, horizon, and ozone region, to obtain data in the 0.28-to-15 μ spectral region; and (5) an interferometer with bolometer detector, horizon-pointed at similar targets in the 8-to-15 μ region.

Meteorological Experiments in Manned Space Flights. In an experiment designed by Nagler and Soles of ESSA, Gemini astronauts took several hundred pictures of cloud systems. These color photographs, taken primarily with 70-mm film, show cloud forms on a scale intermediate between that obtainable from the ground or aircraft and that normally obtained from weather satellites. Of particular interest were the photographs that showed: (1) organized convection (both cellular structures on land and cloud streets), (2) development of diurnal cumulus activity on land, (3) cirrus clouds and their shadows on lower cloud decks, and (4) vortices in strato-cumulus clouds induced by islands or coastal prominences.

Wasko and co-workers at Douglas Aircraft are conducting a study to assess the desirability and functions of meteorological experiments that could be performed by man from orbiting spacecraft. Remote sensing using radiometric techniques is stressed. The study considers the feasibility and utility of many possible experiments and refers to available instrumentation. Man's role and his contributions to the experiments are emphasized.

Interpretive and Supporting Studies. At the National Environmental Satellite Center (NESC), statistical relationships have been established between Tiros 4 (1962 Beta 1) long-wave radiation data and heights of the 500-mb surface. The purpose of the analysis is to provide a means for analysing midtropospheric flow over areas where direct measurements of constant-pressure

height or wind are sparse or absent. Height values at each of 26 points over the eastern Pacific and North America were correlated with Tiros 4 radiation values at 60 points over a larger area extending westward across the Pacific. The screening technique was used to select the best radiation predictors and multiple linear regression equations, expressing 500-mb height as a function of several radiation values at nearby and distant grid points, were derived for each point. The resulting equations were evaluated on both dependent and independent samples; the method seems promising.

A numerical model has also been developed that uses medium spectral resolution radiation measurements to infer the vertical temperature and moisture profiles of the troposphere. It has been shown that with the aid of surface observations, temperature and moisture profiles may be obtained in cloudy as well as clear atmospheres. Errors in the inferred profiles due to modeling constraints or small instrumental errors are within the resolution of ordinary meteorological analysis. Satellite-viewed cloud conditions have been related statistically to the vertically integrated moisture parameter that is used in quantitative precipitation forecasting.

At NESG, synoptic models are being developed that relate the large-scale cloud systems delineated by satellite data to the important dynamic forcing functions producing large-scale vertical motion and extratropical cyclogenesis. This work is part of a general effort to find objective ways to put satellite information into numerical mass-structure analysis and prediction.

Also, at NESG, a large sample of satellite and associated meteorological data has been studied in connection with widespread mesoscale cellular cloud patterns. Two classes of cells, one apparently with ascent in the centers, the other with apparent descent, are found. Experiment and theory indicate the difference might be due to the vertical variation of eddy viscosity.

A cloud-top altitude radiometer, a near-ir grating spectrometer, is being designed at NESG to measure the absorption of solar radiation by the atmosphere in the oxygen A band at 7619 Å. This, together with a knowledge of Sun angle and satellite altitude, will permit a determination of cloud-top altitude. The technique has been tested using a hand-held spectrograph on the Gemini 5 flight. An aircraft version of the eventual unmanned spaceflight spectrometer will be tested soon.

At General Dynamics Convair, a program directed toward better interpretation of meteorological satellite data is under way. A DC-3 aircraft has been instrumented to measure the radiative properties of the atmosphere, of various Earth surfaces, and of stratiform clouds. The infrared energy emitted by the surfaces in the 8-to-14 μ region is being measured both radiometrically and spectrally, as a function of altitude to 20,000 ft. In addition, the total solar flux is measured at the same time. The intensity and polarization of solar visible energy reflected from clouds are measured as functions of wavelength and are related to various measured cloud parameters, including liquid water content and droplet size distribution. An aerial camera has been calibrated to match the spectral response of a meteorological satellite camera, and flown in a U2 to take pictures of the same clouds being observed simultaneously from the DC-3 and by a meteorological satellite.

2. METEOROLOGICAL ROCKETS

The Global Meteorological Rocket Network in 1966. The Meteorological Rocket Network became international with adoption by COSPAR of Resolution 2 in Vienna in May 1966 inviting all countries engaged in meteorological rocket activities to forward their soundings to WDC-A for

publication in monthly WDC-A data reports. Data reports currently include meteorological rocket soundings from Great Britain, Canada, India, Japan, Panama, Argentina, and the United States as is illustrated in the station distribution of Figure 7-4. Some 1770 soundings were reported in 1966, bringing the total number of soundings since the beginning in October 1959 of synoptic rocket probing to 7472.

A principal interest in synoptic rocket studies during 1966 has been extension of knowledge of the diurnal heat wave of the stratopause level discovered by Beyers and Miers and the associated tidal motions of the wind field discovered by Miers. An important addition was an intensive set of diurnal data obtained on April 9-12, 1966, at Ascension Island (8°S). This data confirmed the presence of the diurnal heat wave (12°C) in tropical regions, and added new information on the structure of the tidal circulation at low latitudes.

The high-latitude structure of the stratospheric circulation in summer over Ft. Greely (64°N) was probed with chaff dispersed from special high-energy Loki rocket systems on August 6-8, 1966. Measurements were obtained in the mesopause region, and the easterly circulation was found to increase with height to that level, with maximum winds of over 100 m/sec. Analysis of the chaff fall rates showed a slower fall rate of approximately 5 m/sec in the nighttime sector, a result that is interpreted as indicating vertical upward motions in that noctilucent-cloud region.

A cooperative experiment was conducted by Argentina and the United States on November 11-12, 1966, to sample solar eclipse effects on the stratospheric circulation over Tartagal (22°S). Twelve Arcas rockets were fired on an intensive schedule with complete success in rocket tracking and telemetry performance. The Argentine Chemical meteorological rocket station was moved to Tartagal and operated there under the direction of Valenzuela for this special series of firings. Twelve wind profiles, 9 temperature and 3 ozone profiles were obtained. The series provides data for both diurnal variations and for the nature of an eclipse perturbation on the stratospheric circulation.

The prime objective of the synoptic Global Meteorological Rocket Network is adequate probing of synoptic scale disturbances of the stratospheric circulation. In addition to tidal structure the winter storm period is fertile with synoptic disturbances and thus is of prime interest in the GMRN observational program. After the extremely significant explosive warming event of January 1963, Northern Hemisphere winters have been relatively calm with small-scale interaction along the interhemispheric front producing the usual winter storm period without the gross changes accompanied by explosive warmings.

Grenade Experiments. Thirty-eight acoustic grenade flights, which provide wind and temperature vertical profiles, were flown by NASA during 1966. The experiments, under the direction of W. S. Smith of GSFC, were distributed throughout the year to study temporal and seasonal variations and especially to observe atmospheric structure during the presence and absence of certain atmospheric phenomena. During the latter part of January and early February, there was a total of 10 launches from Pt. Barrow, Alaska, Ft. Churchill, Canada, and Wallops Island, Virginia, to study the circulation and vertical structure of the atmosphere during the presence and absence of auroral activity over Ft. Churchill. Coordinated launches were made from these three sites, several days before, during, and within 24 hr after the occurrence of auroral activity. In addition, diurnal variability data were a by-product of the last two series.

In the latter part of spring a fourth launch site at Natal, Brazil, was added to the launch complex. This site, at 6°S latitude, is expected to provide excellent information on the tropical



Figure 7-4. Global Meteorological Rocket Network, station distribution, 1966 (U.S. Army Electronics Command, Atmospheric Sciences Office, White Sands, N.M.).

atmosphere. Grenade experiments were launched from each of the four sites on May 1 and 3, 1966. This period was selected to coincide with the transition in the circulation over Wallops Island from a westerly flow to an easterly flow.

The characteristics of the atmosphere during the presence and absence of noctilucent clouds were again the subject of investigation during the summer. A total of 11 experiments were conducted from Pt. Barrow, Ft. Churchill, and Wallops Island in the latter part of June and during August in the presence and absence of the noctilucent clouds. This series provided measurements of atmospheric structure and circulation both prior to conditions favorable for the cloud formations and during the period of frequent noctilucent-cloud appearance.

The final series of grenade experiments of the year was devoted to the study of thermally-driven tides. It consisted of four flights from Wallops Island and five from Natal during 24-hr periods in late September and early October. The launches occurred at local noon, sunset, midnight, and sunrise. The soundings will provide comparative equatorial and midlatitude diurnal data for application to and evaluation of theories regarding thermally-driven tides.

During the summer of 1965, a series of grenade soundings at Pt. Barrow was initiated during a noctilucent-cloud display at about 84 km. The first launch was at the time of the noctilucent-cloud display and was followed by two launches during full daylight hours when no clouds were visible (because of the daylight). Two days later, when a cloud display was definitely not occurring, a fourth experiment was launched as a control measurement. The four vertical temperature profiles, except for minor variations, are the same with a steep uniform decrease in temperature from the stratopause to the mesopause and a minimum temperature at the mesopause of 140°K to 132°K at about 85 km. The complete absence of diurnal effect in these soundings is a result of the almost continuous sunlight at Pt. Barrow in August.

The temperature soundings at Kronogård, Sweden (66°N) in 1963, and at Ft. Churchill, Canada, in 1964 and 1965, during noctilucent-cloud displays were similar to the soundings at Pt. Barrow. In each case where the noctilucent clouds were observed, the temperature at the mesopause was less than 140°K . Thus, since such low temperatures occur in both the presence and absence of these clouds, the low temperatures are a necessary but not sufficient condition for the existence of the clouds, and an increase in the moisture content of the atmosphere may be necessary at these altitudes during the occurrence of low temperatures.

On the basis of the analysed data from launches last year and in previous years, the following conclusions concerning the temporal variations in the temperature and wind structure of the mesosphere can also be drawn:

- (1) The stratospheric warming observed over Barrow in mid-winter 1965 can be explained in terms of the circulation features at 50-km altitude. A southward migration of the polar vortex combined with the building of the Aleutian anticyclone over the Alaskan Peninsula was seen to bring warmer air to Barrow during an eight-day period and re-establishment of the polar position of the vortex restored the colder flow to Barrow four days later.

- (2) The polar vortex, the Aleutian anticyclone pressure systems, and the planetary scale waves dominate the circulation of the lower mesosphere in winter in the Northern Hemisphere. The wind and temperature fields are subject to gradual major changes which occur over a period of days or weeks. Smaller variations result from the diurnal cycle, but no middle-scale, short-term variations were detected, largely due to the sparse data coverage. Above 70-km altitude, tidal forces and possibly internal gravity waves exert the major influences on wind and temperature structure. These variations are of short duration, on the order of hours.

- (3) Wavelike structures in the mesospheric temperature profiles of middle- and high-latitude sites appear to exist only in wintertime, and their amplitude of oscillation increases with

increasing latitude. Conversely, these variations appear to be completely suppressed under the typical high-latitude summertime regime which is characterized by a steep uniform temperature-lapse rate, easterly circulation, and an inferred upward motion.

Falling-Sphere Studies. During 1966, AFCRL conducted four successful falling-sphere experiments on Nike-Apaches launched at White Sands on August 1 and 6. In addition, data from four flights in November and December 1965 (three at Ft. Churchill, one at Eglin AFB) were analysed and results reported at the May 1966 COSPAR meeting. Densities were measured and temperatures and pressures were deduced from these results. The Eglin data agreed well with the models for that latitude. The measurements at Ft. Churchill were very interesting and, although the general agreement with the models was good, the data showed an unpredicted fine structure of fluctuations. This was most obvious in the temperature profiles and it may correlate with the moderately high geomagnetic activity which existed at the time of the measurements.

Peterson and McWatters at the University of Michigan examined data from seven recent falling-sphere flights for evidence of solar heating near the mesopause. Day-night pairs of soundings in summer at Kwajalein and Wallops Island and in winter at Wallops Island indicated a daytime increase in density of about 15%. It appears that sources of heat other than solar may be of equal or greater importance near the mesopause.

Pitot-static Experiments. Upper-atmosphere density profiles were measured with five pitot-static tube experiments in 1966 conducted in NASA Nike-Apache rockets by Horvath of the University of Michigan. The first two flights were made from Ascension Island on February 27. The purpose was twofold: to provide re-entry atmospheric-density data for the Apollo flight and, by launching a second experiment 12 hr later, to evaluate diurnal changes in the structure of the tropical atmosphere. The density profile for the Apollo re-entry was obtained, but during the second launch operation, the rocket's second stage failed and no data were obtained. The other three pitot-static tube experiments were launched from Ft. Churchill and Wallops Island during August in conjunction with other experiments. The first (NASA 14.289UM) was conducted within 45 min after an acoustic grenade experiment and each of the other two (NASA 14.285UM and .286UM) was launched in parallel with the launch of a thermosphere-probe experiment. These experiments, when combined with data from radiosondes and the smaller meteorological rocketsondes, will provide a continuous profile of the vertical structure of the atmosphere from the surface to about 300 km. This information is applicable to the analysis of the turbulent energy exchange between atmospheric regions such as the mesosphere and the thermosphere.

Data obtained from eight pitot-static tube soundings made from aboard the U.S.S. *Croatan* during March and April 1965 off the west coast of South America (Tropic of Capricorn to 60°S) and from two soundings made from Ascension Island (8°S) were analysed and plotted (Figure 7-5). The analysis shows a uniform stratosphere between 15- and 40-km altitude. Another feature is that the stratopause is warmer in the low and high latitudes than in the midlatitudes. The most spectacular variations in the cross section appear above 80 km. The mesopause starts near 80-km altitude at the equator, but between 6°S and about 35°S it is much higher (approximately 100 km) and over 20°K colder than at the equator. The lower and warmer mesopause exists again between 38°S and 48°S but becomes higher and colder again south of 48°S.

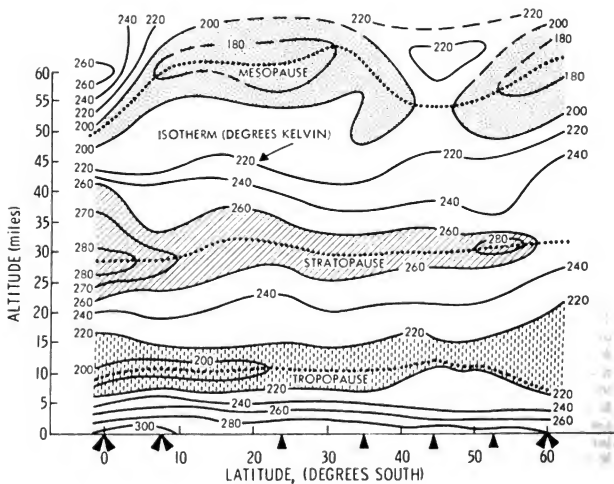


Figure 7-5. Temperature cross section, March-May 1965, obtained from eight rocket soundings from the U.S.S. *Croatan* off the west coast of South America and from two soundings from Ascension Island. $\blacktriangle$ denotes sounding (NASA).

Data Analyses. During 1966, analyses were completed by NASA of data obtained at Wallops Island in September 1965. The experiment was designed to determine the diurnal temperature and wind variation and to detect possible errors in rocketsonde temperature measurements in the upper stratosphere. Fourteen HASP and two Arcas rockets, carrying WOX-1A and Arcasonde-1A instrumentation, respectively, were launched during a 39-hr period. Analysis of the observed rocketsonde temperatures indicates a diurnal variation ranging from about 3°C at 30 km to 9°C at 48 km. Marked differences in the temperatures measured by rocketsondes launched prior and subsequent to sunrise and sunset suggest that a portion of the variation may not be real, but a function of instrumental error. Support for this inference is provided by computations utilizing the rocketsonde winds as an independent means of determining the diurnal temperature wave. The results, which are consistent with theory, yield an amplitude about half that of the observed variation in the 35-to-45 km layer. Temperatures obtained from several rockets launched within a short time interval disclose that the HASP (WOX-1A) system is capable of reproducing a given temperature profile with relatively small random error. In addition, Arcas (Arcasonde 1A) measurements appear compatible with those of the HASP. However, a definite discrepancy was found to exist between rocketsonde temperatures and those reported by the supporting rawinsonde observations.

The meteorological program of the NASA Mobile Launch Expedition aboard the U.S.S. Croatan in the Southern Hemisphere during the IQSY included on-board meteorological rocket measurements of wind and temperature to altitudes of 65 km. Data from 32 of these soundings have been analysed by Chamberlain and Manning in connection with the circulation of the upper atmosphere in the Southern Hemisphere.

These meteorological data were also utilized by Finger and Woolf of ESSA to investigate the early autumn stratospheric circulation of the Southern Hemisphere. Time-height and cross-section analyses which indicate the vertical and areal extent of the developing wintertime polar vortex were made. A comparison was made between this cyclone and that of the Northern Hemisphere at a similar stage of development. Additional sets of analyses illustrate segments of the circulation patterns in both hemispheres along the 78th meridian at the time period of the Croatan observations. Although the observations were limited in number and restricted in time, the following inferences have been drawn from the analyses:

(1) The middle and upper stratospheric circulations of both hemispheres behave in a similar manner during the early autumn season. In the case of the Northern Hemisphere, several series of synoptic analyses indicate that high-latitude autumnal cyclogenesis progresses rapidly upward from 20 km or below to at least 55 km. Furthermore, once the polar cyclone is established, intensification and expansion proceed most rapidly at the higher levels. Recent information for the high latitudes of the Southern Hemisphere, although restricted in vertical extent, confirms the upward progression of cyclogenesis to at least the 20-mb level. The Croatan rocketsonde data, although restricted in latitudinal extent, tend to substantiate the accelerated intensification of the Southern Hemisphere polar cyclone at the higher levels.

(2) The analysis accomplished with the Croatan data supports the proposition that the Southern Hemisphere polar cyclone is more intense than that of the Northern Hemisphere.

(3) A degree of symmetry exists between the flow patterns of the two hemispheres during portions of the equinoctial periods. Results for the specific case investigated indicate a predominantly westerly flow above about 45 km. Below that level to near the tropopause a band of easterlies was situated nearly symmetrically about the equator. The greatest latitudinal extent of these easterlies occurred in the layer from about 26 to 36 km. More data will be

required to ascertain whether the indicated interhemisphere symmetry exists during all phases of the quasibiennial wind oscillation and also during the various modes of Northern Hemisphere vernal circulation change.

The compatibility of rocket observational results obtained 1962-65 in the Arctic and Antarctic was examined by Quiroz of the USAF Environmental Technical Applications Center. Atmospheric densities were derived from rocket pressure-gauge and thermistor observations at Heiss Island, Franz Josef Land (81°N) and from rocket thermistor observations at Thule, Greenland (77°N) and McMurdo Sound, Antarctica (78°S). Climatological statistics were then obtained, representative for 80°N at altitudes between 30 and 50 km. It was observed that the amplitude of the seasonal variation of density in the upper stratosphere continues to increase northward from 60°N . At 80°N it is approximately twice as great as at 60°N . At the more northerly latitudes, departures from standard density range from 45% less than standard in January to 30% greater than standard in July, based on the monthly means. At 50 km the seasonal range exceeds the maximum range previously noted near 70 km at 60°N . A preliminary study of the correlation between the density in the upper stratosphere and the temperature and pressure of the lower and middle stratosphere, respectively, showed a high correlation, supporting the argument of the influence of stratospheric warming on the density regime. The 30-km density averages determined from rocket data in winter near 80°N were observed to be lower than the corresponding values based on radiosonde data. The difference is believed to be due to radiosonde bias in favor of warm temperature (high density) conditions.

Meteorological Rocket Systems Developments. In continuing its scientific exploration of the atmosphere above 30 km, NASA has utilized two classes of sounding rockets. The larger research rockets of the Nike-Cajun and occasionally the Aerobee class are used to obtain data up to 100 km and to develop new techniques for measurements in that region. The smaller operational sounding rockets of the Arcas and Loki class continue to obtain data routinely up to 60 km while testing new components and systems. The developmental work is aimed toward achieving an inexpensive meteorological rocket-sounding system, capable of reliable routine launches and amenable to the requirements for range support, meteorological research, and network operation. Such a system is required for adequate synoptic coverage of the upper atmosphere.

NASA and the U.S. Army are cooperating in the development of a new 60-km vehicle. The falling-mass hazard inherent in spent vehicles must be eliminated in the course of the work in order to extend the number of locations at which such vehicles can be used. NASA and the Army are therefore funding background development work on both frangible and self-consuming rocket cases. NASA is also supporting research on an operational meteorological system with a 100-km altitude capability. Such an extension will, for some parameters, require new sensors since the reduced density at those altitudes requires a different measurement technique.

During 1966, a series of 23 rocketsondes was launched in coordination with 12 radiosondes over a period of about 60 hr. Data were obtained on (1) instrumentation errors in rocketsondes due to the effects of solar radiation, (2) differences between simultaneous measurements by radiosondes and rocketsondes, and (3) diurnal temperature variations above 30 km. Work is also continuing on further improvements to the payloads, including development of an extended temperature measurement capability to 100 km. Development of solid-state power oscillators and transmitters and of bolometer circuits with very small time-constants is also part of the payload improvement effort. Parachutes suitable for use at altitudes at or above 60 km are being designed.

About 175 operational development-type sounding rockets were launched in 1966 in connection with this program. The meteorological data from these flights were also used to support range operations and were made available to other agencies.

The miniaturized rocket-sounding system known as the Judi-Dart or the PWN-8A developed by AFCRL has been accepted for routine use at the test ranges and by the Meteorological Test Network. This effort included qualifying a slightly more powerful booster vehicle than the Judi. The PWN-8A, with its much lower cost and less restrictive launching conditions, will facilitate world-wide measurements of temperature, density, and wind to 60 km. Development work on a Loki transponder sonde has been encouraged by AFCRL's success in developing the AN/DMQ-9 transponder now being used operationally in the larger Arcas rocket.

Excessive fall velocities and wild oscillations of the sonde after ejection degrade rocketsonde data. In an attempt to eliminate this problem, the Ballute, a ram air-inflated retardation and stabilization device combining the aerodynamic advantages of the balloon and the parachute was substituted for the usual parachute on many Judi and Arcas flights. The result was a dramatic improvement in data quality and an encouraging decrease in fall rate.

Development of a standard high-altitude meteorological rocket system has progressed. One promising system, the Sparrow-Arcas, performed well in test soundings to 150 km and costs substantially less than Nike-boosted vehicles. Further savings are expected from a Viper-boosted dart with a 140-km apogee now being readied for test with the Robin falling sphere. The standard uninstrumented falling sphere, the 60-km Robin, was redesigned to measure density from 100 km downward and was flown on Sidewinder and Sparrow-boosted Arcas rockets. It is now being readied for Viper-Dart flights. In addition, the AFCRL 1-m diameter accelerometer-equipped sphere was successfully flown on a Nike-Iroquois rocket. It measures density to 150 km. A smaller, 60-cm version, partially instrumented and successfully flown on a Sparrow-Arcas rocket, will measure density at 130 km. AFCRL development of a "spin-rate decay" sensor continues. A new approach, taken prior to the flight of a plastic rotor prototype, uses spinning wires.

Moon, Planets, and Meteorites

1. MOON

Surveyor Program. The objective of the Surveyor program is to soft-land instrumented spacecraft (Figure 8-1) on the Moon to gather basic scientific data and to obtain engineering information of importance to the Apollo manned lunar landing program. The Surveyor project is managed for NASA by JPL.

Surveyor 1 (1966-45A) was launched on May 30, 1966. Approximately 16 hr after launch, a midcourse-correction maneuver was executed, moving the landing point to an area north of the crater Flamsteed in Oceanus Procellarum. The automatic closed-loop landing sequence was successfully completed at 0617:36 UT on June 2, 1966. Telemetry data indicated that the spacecraft touched down at a vertical velocity of approximately 10 ft/sec at 2.41°S , 43.34°W lunar coordinates.

Surveyor 1 transmitted 10,338 high-quality pictures during the remainder of its first lunar day (12 Earth days) and an additional 899 pictures during its second lunar day. These pictures showed that the spacecraft had landed on a dark, relatively smooth, barren surface, encircled by hills and low mountains. The larger craters observed resemble, in shape and distribution, those seen in the Ranger photographs, indicating that the Surveyor 1 site is representative of a mare surface. The surface is composed of granular material having a wide range in sizes. Figure 8-2 is a closeup of a Surveyor footpad and the disturbed lunar material around it. The material ejected by the spacecraft footpads consists of lumps that are probably aggregates of much finer grains below the resolution limit of 0.5 mm. These aggregates show that the fragmented material on the local lunar surface is at least slightly cohesive. The footpad penetrated 1-1/2 to 3 in. below the undisturbed surface, which is compatible with a dynamic bearing-strength of 6 to 10 psi indicated by strain gauges on the landing gears.

Surveyor 2 (1966-84A) was launched on September 20, 1966. It did not accomplish its soft-landing objective because of a propulsion problem encountered when attempting to make the midcourse correction. Surveyor 3 (1967-35A), carrying television cameras and a surface sampler, soft-landed on the Moon on April 20, 1967.

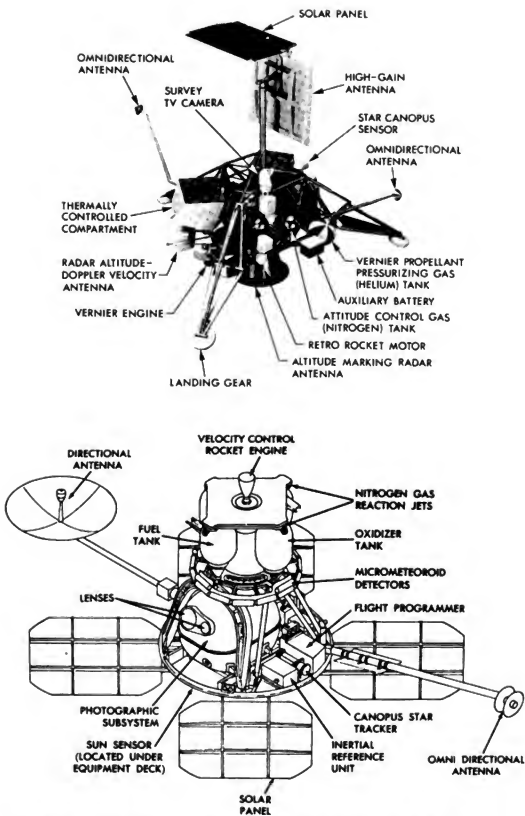


Figure 8-1. Diagrams of the Surveyor (top) and Lunar Orbiter (bottom) spacecraft (NASA).

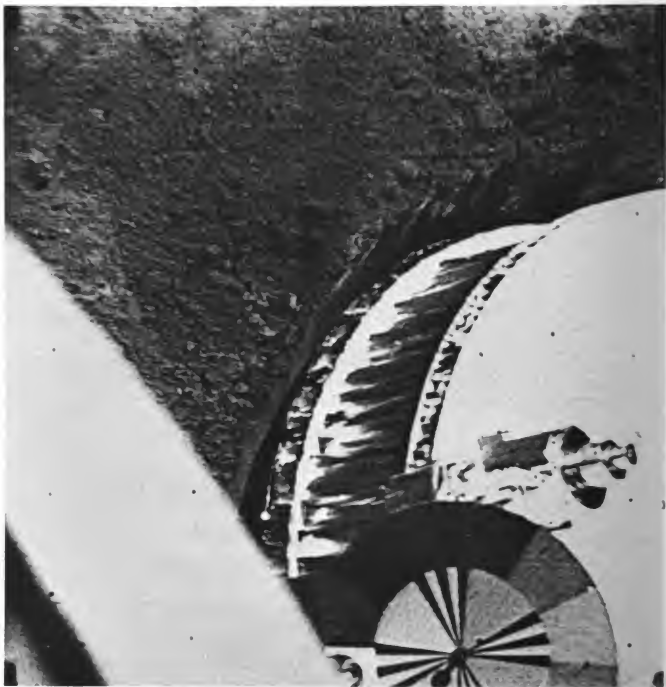


Figure 8-2. Narrow-angle photograph taken by Surveyor 1 of its own foot pad 2 on the lunar surface (NASA).

Lunar Orbiter. Lunar Orbiter 1 (1966-73A) and Lunar Orbiter 2 (1966-100A) were launched from Cape Kennedy on August 10 and November 6, 1966, respectively. The spacecraft (Figure 8-1) carried a photographic system consisting of one medium-resolution and one high-resolution camera, a film processor, and film readout. They also carried sensors to measure the micrometeoroid flux and radiation level in the immediate vicinity of the Moon. The primary objective of the two missions was to obtain detailed photographic information on various lunar surface areas to assess their suitability as landing sites for manned Apollo spacecraft and automated Surveyor spacecraft, and to improve knowledge of the Moon. The secondary objectives were to obtain environmental measurements and precise trajectory data for use in improving the definition of the lunar gravitational field. After a 91-hr transit, the spacecraft were placed in a 12° -inclination orbit about the Moon, 1850-km apolune and 200-km perilune. After several days, the spacecraft were placed in a final 12° -inclination orbit, 1850-km apolune and 46-km perilune, for lunar surface photography.

Lunar Orbiter 1 obtained 8-m resolution photographs of 9 potential primary Apollo landing sites and 7 potential secondary Apollo landing sites; 24-m resolution photographs of the equatorial region at the east limb of the Moon; and detailed photographs of the far-side lunar surface with resolution better than 50 m.

Lunar Orbiter 2 photographed 13 other potential primary Apollo landing sites at 1-m and 8-m resolution. It also covered 17 other sites of interest, including oblique views of the crater Copernicus (Figure 8-3) and far-side features not photographed by Lunar Orbiter 1 (Figure 8-4).

The micrometeoroid flux recorded near the Moon was similar to that found near the Earth. The total accumulated radiation dose near the Moon was about 3 mr after a period of 35 days, during which no major solar-flare-proton events occurred. Preliminary analysis of tracking data was used to compute some of the higher coefficients of the lunar gravitational potential. Preliminary results indicate that lunar gravitational potential is smoother than had been expected.

The Lunar Orbiter photographs will be made available for detailed study through the NASA Space Science Data Center, GSFC.

Ranger Analysis. After considerable analysis of data from Rangers 8 and 9, the report "Experimenters' Analyses and Interpretations" was published by Jet Propulsion Laboratory in March 1966 as JPL Technical Report No. 32-800.

According to Shoemaker, the most significant new information about the fine structure of the lunar surface obtained from the Ranger 8 and 9 missions includes: (1) the frequency distribution and morphology of small craters on several different classes of lunar terrain; (2) the morphologic details of very small craters that are related to the mechanical properties of the lunar surface material; (3) the distribution and orientation of small lineaments and their spatial relation to certain types of craters, especially on the floor of Alphonsus; and (4) the small topographic details of broad, sloping surfaces, such as the walls of Alphonsus.

The report includes an analysis by the Ranger team at the University of Arizona's Lunar and Planetary Laboratory. This analysis is based in part on new photography with the 61-in. NASA telescope and the results of several field trips to the New Mexico and Hawaii lava fields. The 61-in. photography includes new determinations of the distribution of color over the visible lunar surface by Whitaker. Included are discussions of: (1) the bearing strength of the lunar surface, determined to be of the order of 1 kg/cm^2 , the first such determination made (a more accurate determination has been made from Surveyor 1 for a different mare;



Figure 8-3. An oblique picture of the crater Copernicus taken by the high-resolution camera on Lunar Orbiter 2. The spacecraft was 46 km above the lunar surface and about 246 km due south of the center of Copernicus when the photograph was taken (NASA).

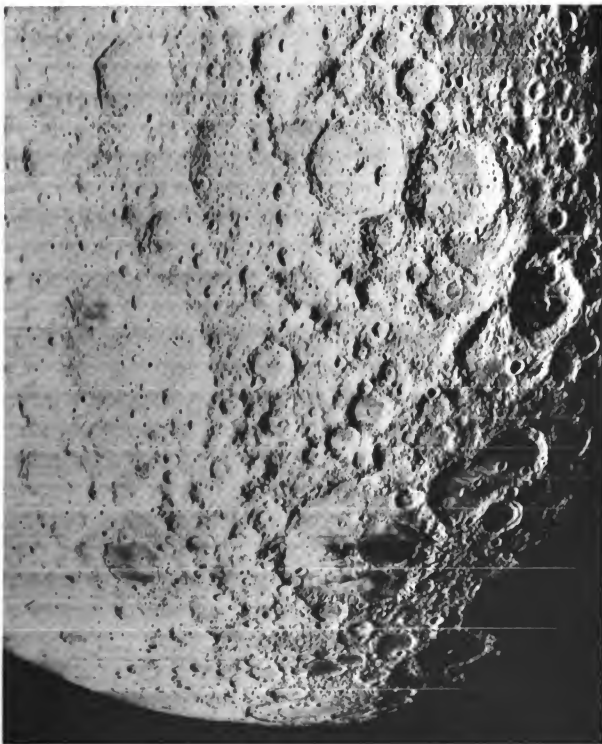


Figure 8-4. Photograph of an extended area on the southern part of the Moon's far side taken by Lunar Orbiter 2. The Moon's equator is roughly along the top of the photograph. The area covered is about 10^6 sq km. The smallest features which can be detected are about 0.3 km across. The picture was taken from an altitude of about 1500 km. The northeast corner of the picture is located at $173^{\circ}\text{E}, 5^{\circ}\text{N}$, lunar coordinates, and the northwest corner is at $138^{\circ}\text{E}, 1^{\circ}\text{N}$ (NASA).

the result was approximately half that obtained from Ranger 9); (2) the frequency distribution of sharp craters in the maria and the interpretation of these as due to impact; (3) the presence of small domes and their significance for the structure of the mare surface, and the presence and significance of sinuous rilles; (4) the presence and significance of clearly-bounded lava fields, showing flow fronts, in Mare Imbrium and elsewhere; and (5) a summary of the evolution of the crater forming process on the Moon.

A three-layer model of the lunar maria has resulted. The upper meter or so is believed to be of low density, disturbed by subsequent small impacts and resting on the remainder of an original low-density layer having a total thickness of 8 to 10 m. This low-density layer is thought to have been caused by the vacuum deposition of molten lava in a low gravitational field. Below this layer, a more solid rock formation is believed to exist. The 8-to-10 m low-density layer had previously been recognized from radar returns at long wavelengths. It may also be indicated by certain aspects of the crater-forming process. It appears erroneous, however, to assume that the entire low-density layer has been reworked by subsequent impact. The meter-scale lineaments, domes and, more recently, the results of Surveyor 1 all seem to show that the disturbed layer of the maria is only about 1-m thick.

Hartmann at LPL continued a program of measurements from the Ranger and Zond records of diameters and surface densities of lunar craters. A series of measurements of craters on the Alphonsus wall, floor, and central ridge was completed. In addition, rectification of the Zond 3 (1965-56A) photography shows that the great crater chains on the far side are part of the radial system of the Orientale basin. Strom initiated a study of the spatial distribution of lunar craters. Maps were prepared showing the various size intervals and classes of craters from the four Arthur catalogs in the LPL Communications series, and chi-square tests were made to determine whether the various crater types were randomly distributed. Preliminary results indicate that craters from 4 to 8 km are non-randomly distributed, but craters of diameter greater than 8 km are randomly distributed.

Other Studies of the Lunar Surface. A 60-cm balloon-borne telescope was launched by AFCRL from Holloman AFB on February 4, 1966, and reached a float altitude of 31.7 km. Using a prism spectrometer and thermocouple detector, the first lunar infrared emission spectrum (8.5 to 22.5 μ) recorded from balloon altitudes was obtained. Emission from the target area on the Moon, which was a 400 x 250 km area in the Central Highlands between the craters Abulfeda and Sacrobosco, showed no spectral information above an estimated 3% detection level, which result is consistent with those of previous ground-based studies.

Later in the year (November 27, 1966), an Aerobee rocket (AG3.257) with a lunar-pointed payload, consisting of a circular variable-filter infrared spectrometer, was launched from Fort Churchill. This experiment obtained the first infrared emission spectra of the Moon from completely outside the atmosphere. The instantaneous target diameter on the Moon was 960 km, with a 2-Hz wander of approximately 10 arc min. Individual spectra have a signal-detection level of approximately 1%. These data are still being reduced.

Planned Lunar Studies. Four more Surveyors are scheduled to be launched during 1967, the next to carry the same instrumentation as Surveyor 3, and the last three to carry, in lieu of the surface sampler, an α -backscatter experiment to perform elemental analysis of lunar surface material. Three more Lunar Orbiter photographic missions are planned for 1967.

A new infrared balloon-borne spectrometer, utilizing a circular variable wedge filter and a liquid-helium-cooled, copper-doped germanium detector, that will lower the signal detection level below 1%, has been assembled at AFCRL. It will be flown on the 60-cm balloon-borne telescope system in the first quarter of 1967.

Plans for an expanded and improved edition of the Rectified Lunar Atlas are being made at LPL. As Orbiter photography, medium- and high-resolution vertical and oblique, accumulates such an Atlas should find increasing use.

2. MARS

Analyses of Mariner 4 photography were made by Binder and Hartmann of LPL. Binder's report, concerning cratering and lineaments was published in Science. Hartmann's report, on formation, erosion, and age of craters, was submitted to Icarus. Both reports concluded that the Martian craters date back as far as 3×10^9 years, an order of magnitude older than preliminary published estimates of other authors.

The University of Pittsburgh has constructed another theoretical model of the Martian atmosphere and ionosphere to account for the results of the Mariner 4 occultation experiment. In this model the atmosphere is mainly CO_2 at low altitudes, moderately dissociated and the ionosphere is an F_1 region.

The Space Sciences Department of the Douglas Aircraft Company is conducting studies of the transmission of uv light through the Martian atmosphere in the 1000-to-4000 Å spectral region. This study consists of computations of the volume scattering and optical thicknesses at different altitudes of a Martian atmospheric model which was constructed by Douglas on the basis of information obtained from the Mariner 4 results. It has been determined that the attenuation of solar uv radiation between 3000 and 4000 Å is only a few percent; therefore, an appreciable amount of uv radiation reaches the planet's surface. In the 2000-to-3000 Å region, the attenuation of direct solar radiation is about 20% and is caused by molecular scattering and ozone absorption. For the shorter wavelengths, although the scattering effects are stronger, the atmosphere is entirely opaque to solar radiation because of absorption of short uv radiation by carbon dioxide.

3. PLANNED STUDIES OF VENUS IN 1967

A Mariner spacecraft built to support the 1964 Mars launch (Mariner 4) has been modified to fly by Venus in mid-1967. The spacecraft will be aimed for closest approach to Venus of 3000 km, as compared with 35,000 km for Mariner 2. Interplanetary particles and fields will be studied with instruments similar to those aboard Mariner 4, but during a different phase of the solar cycle, and the probe will provide data on the magnetic and radiation environment near Venus at a much closer range, thus complementing the Mariner 2 measurements. A uv photometer will derive density and distribution of atomic oxygen and atomic hydrogen in the planet's upper atmosphere. These data in conjunction with those from a radio occultation experiment using 50 MHz, 425 MHz, and S-band signals are expected to provide the basis for constructing a

reasonable model of the Cytherean atmosphere. Improvements in the technology and equipment for tracking this vehicle should allow redetermination of the mass of Venus with an accuracy greater by a factor of 100 than that possible in 1962.

In a complementary program, Kitt Peak National Observatory plans to fly its separable payload-orientation system on an Aerobee rocket (KP 3.20) in November 1967. The instrument will be a 33-cm Cassegrain telescope with a grating spectrometer to investigate the spectrum of Venus in the uv wavelength range 1600 to 3200 Å.

4. METEORITES

Satellite Data. The three Pegasus spacecraft (1965-9A, 1965-39A, and 1965-60A) orbited by NASA's Marshall Space Flight Center have recorded several thousand meteoroid penetrations and have established penetration frequencies of $.00487/\text{m}^2/\text{day}$ for the 0.4-mm detector, $0.0209/\text{m}^2/\text{day}$ for the 0.2 mm-detector, and $0.188/\text{m}^2/\text{day}$ for the 0.038 mm detector. These values are uncorrected for Earth-shielding. All spacecraft are still functioning, but Pegasus 1 is no longer returning useful meteoroid data. It has been decided to override the all-systems-off timer on these spacecraft in order to accumulate additional data on seasonal and shower activity.

The Pegasus data appear to be consistent with the findings of Explorer 16 (1962 Beta Chi 1) and Explorer 23 (1964-74A), both with respect to puncture frequency and to difference in puncture frequency with thickness. The meteoroid size distribution obtained by Pegasus is very similar to that inferred from earlier zodiacal light measurements for an assumed heliocentric dust distribution. This agreement is in sharp contrast with earlier estimates based on acoustical impact detectors that indicated as much as 10^4 times higher influx rates than expected from deep-space number density estimates. The integrated mass influx on the Earth estimated from the penetration experiments is 100 to 300 metric tons per day. The necessary interpretative comparison of the penetration data with other kinds of data was made using a target-sheet-penetrability formula that was derived on the basis of recent laboratory hypervelocity impact data and theoretical considerations developed at NASA's Ames Research Center. The logarithm of the mass-cumulative influx of cometary particles/ m^2/sec was found to be a non-linear function of the logarithm of the least particle mass in grams. With common logarithms, a cubic polynomial with -14.52, -1.406, -0.0490, and -0.00074 for the coefficients of respective ascending powers fits the data and seems most appropriate for extrapolation over the mass range for cometary particles.

AFCRL placed some ultraclean meteoroid-collection surfaces on the Gemini 9 and 12 space capsules. These surfaces were exposed for several hours in space and later returned to Earth for laboratory study. Several events believed to be the result of meteoroid impact have been observed. In one instance, a particle that penetrated two thin nitrocellulose films was found, photographed, and chemically analysed. The number of impacts counted is low and preliminary numbers tend to support recent rocket data. This type of satellite experiment appears to be the best approach to meteoroid collection because the exposure times can be significantly increased over those obtainable with high-altitude rockets. Further experiments are planned by AFCRL for the Apollo series.

Rocket Data. Micrometeorite-particle collection surfaces from NASA's Project Luster—Aerobee rockets flown in November 1965 (NASA 4.199NA and 14.78UA) and August 1966 (NASA 14.170UA)—have been analysed at AFCRL with an electron microscope. For particle sizes below $0.5\text{-}\mu$ diameter, the number of particles per unit area is several orders of magnitude above that reported on the 1961 Venus Fly-Trap. However, the particle count on the control surfaces in this size range is also several orders of magnitude higher. The net result is that there is very little difference between control and flight surfaces, and in some cases, the control films have even more particles than the flight films. For particles larger than $0.5\text{ }\mu$, the particle counts are lower than those reported for the Venus Fly-Trap. One reason for the differences in count is believed to be the fact that a clean room was not used in analysing the Venus Fly-Trap experiment in 1961. Clean rooms are very effective in eliminating particles larger than $0.5\text{ }\mu$. Unfortunately, they may also tend to increase the number of collected particles below $0.5\text{ }\mu$. Another factor leading to the reduction of meteor-flux estimates is a re-evaluation of the single and double shadow technique for distinguishing between real and contaminate particles. It has been shown that this technique becomes ineffective for identifying particles in the size range $0.1\text{ }\mu$ and below. The result of these studies is that the published fluxes for particles below $0.5\text{ }\mu$ may be several orders of magnitude too high.

For particles between $0.5\text{ }\mu$ and about $2\text{ }\mu$, an electron microscope must still be used for scanning and a practical limit is imposed because of the small amount of area that can be scanned with an electron microscope in a reasonable amount of time. Because the flux of particles drops off steeply as the size increases, very few particles in this size range are ever counted and rather large statistical errors may be introduced. Above $2\text{ }\mu$, optical scanning methods can be used and larger areas may be scanned in reasonable amounts of time. Furthermore, the larger size of the particle also allows the use of other methods, i.e., chemical analyses, for distinguishing between real particles and contaminants. A careful optical study of the surfaces exposed on the two Luster flights, however, indicates that the fluxes for particles $2\text{ }\mu$ and larger are also at least an order of magnitude below the Venus Fly-Trap 1961 results.

The Space Sciences Department, Douglas Aircraft Company, is studying particles collected by high-altitude rockets to (1) discover criteria to distinguish particle origin (terrestrial or extraterrestrial), (2) determine space-radiation effects, and (3) determine the nature and abundance of micrometeorites in the vicinity of Earth. A specially developed collecting substrate, designed to withstand heating to 1000°C , was flown on a Project Luster rocket (NASA 4.199NA) on November 16, 1965 (63 to 144 km altitude). The first efforts were devoted to determining if crystalline damage from space radiation, as evidenced by restoration of electron-diffraction patterns by heat annealing, could be used to distinguish micrometeorites from terrestrial particles. Heating tests were completed on one large swarm of 58 fluffy particles and on two individual particles. Of these, only one particle showed evidence of possible radiation-damage annealing, but it also showed some morphologic changes. Since all of these particles could have been contaminants, more particles will have to be studied before the radiation-damage criterion for micrometeorites can be established or firmly rejected. The heat-produced morphologic change discovered may also prove to be useful in distinguishing micrometeorites from contaminants.

Meteoritic debris during the peak of the Orionids meteor shower was collected in an Aerobee 150 flight (NASA 4.161NA) from White Sands on October 22, 1966. The experiment, conducted by Farlow of NASA Ames Research Center, used three deployable module support arms,

each arm holding four module trays on which the meteoritic debris was entrapped upon impact. The modules were vacuum-sealed at recovery and are being analysed.

Another Aerobee 150 experiment was conducted by Berg, McDonnell, and Aikin of GSFC on October 25 from White Sands to recover physical evidence of hypervelocity micrometeoritic impacts, measure the ionization and momentum characteristics of cosmic-dust impacts, and measure electron densities below 120 km using aluminum-coated glass cylinders, impact ionization sensors, and a Smith probe. This launch (NASA 4.195GA-GI) was coordinated with that of Nike-Cajun NASA 10.181AI a half hour later, carried out by Whipple of ITSA, to obtain correlative data on electron and ion densities in the D region. Good data were obtained on this flight, but owing to premature severance of the exposure cylinders in the cosmic-dust experiment, only a complete examination of the cylinders will determine whether or not the surfaces were damaged by the severance blast.

The SAO network for simultaneous radar and optical observation of artificial and natural meteors obtained one radar echo from a steel pellet fired back into the atmosphere at 10.9 km/sec from a Trailblazer rocket launched by NASA at Wallops Island. The echo was consistent with an ionizing efficiency at this low velocity roughly one third of the Verniani and Hawkins estimate (Astrophys. J. 140, 1590, 1964), which was derived from observations at normal meteor velocities.

Life Sciences

1. GEMINI PROGRAM

Medical Results. The flight of Gemini 12 (1966-104A) in November 1966 brought to a conclusion the second in the series of three United States manned space-flight programs. The major medical objectives of the Gemini Program were to accumulate experience in the physiological reactions of crew members during long-duration missions and to compile medical data necessary for planning the manned lunar-landing program, Apollo. The major medical results of the Gemini Program may be summarized in terms of the following body systems:

(1) Central Nervous System. Adequacy of function of the central nervous system was evaluated in terms of total performance. The performance of the crews was excellent on all missions and particularly noteworthy on those involving extravehicular activity. There were no inflight vestibular symptoms (despite the fact that a number of astronauts developed motion sickness while in the spacecraft on the water at the conclusion of the mission) and no evidence, inflight or postflight, of psychological disturbances. Pre- and postflight caloric vestibular function studies showed no changes and no significant changes were noted in special studies of the otolith response.

(2) Respiratory System. Rather high respiratory rates were noted during heavy workloads in the extravehicular activity. Pre- and postflight x rays did not reveal atelectasis, and pulmonary function studies before and after the 14-day mission showed no alterations.

(3) Cardiovascular System. Heart rates peaked at launch and at re-entry, normally reaching higher levels during the re-entry period. The mid-portions of all missions were characterized by more stable heart rates at lower levels with adequate response to physical demands. Blood pressures obtained in the Gemini Program showed systolic and diastolic values remaining within normal ranges, including those taken at the time of re-entry. No significant changes occurred throughout as much as 14 days of space flight.

The only abnormalities of note in the electrocardiograms have been very rare premature auricular and ventricular contractions. There have been no significant changes in the duration of specific segments of the electrocardiogram. Some insight into the electrical and mechanical phases of the cardiac cycle was gained during a few of the Gemini flights through synchronous phonocardiographic and electrocardiographic monitoring. In general, wide fluctuations in the duration of the cardiac cycle were observed throughout the missions although these remained within acceptable physiological limits. Fluctuations in the duration of electromechanical systole correlated closely with changes in heart rate. Stable values were

observed for electromechanical delay, with shorter values observed during the intervals of peak heart rates recorded during lift-off, re-entry, and extravehicular activity. Higher values observed for the duration of systole and for electromechanical delay in certain of the astronauts suggest a preponderance of cholinergic influences (vagal tone). An increase in sympathetic tone (adrenergic reaction) was generally observed during lift-off, re-entry, and in the few hours preceding re-entry.

In contrast with the Mercury results, orthostatism resulting from the Gemini missions has been detectable only by means of passive tilt-table provocation. If postflight increases in heart rate during tilt are expressed as a percent of the preflight tilt heart rate for each of the Gemini mission crews, the postflight increases were from 17 to 105% greater than those exhibited preflight. Leg-volume changes during postflight tilts were also universally greater than preflight values, the increase ranging from 12 to 82%. Average resting heart rates were from 18 to 62% higher after missions. In spite of the higher resting pulse rates, the changes resulting from tilt were still greater.

(4) Blood. Significant increases in white blood-cell counts manifested as an absolute neutrophilia followed most flights, with return to normal within 24 hr. Hematological data derived from 4-, 8-, and 14-day Gemini missions demonstrated a hemolytic process originating during flight. The variables that must be considered as possible causative factors are hyperoxia (i.e., 166 mm O_2 at the alveolar membrane), lack of inert diluent gas (i.e., nitrogen), relative immobility of the crew, dietary factors, and weightlessness. Of the factors stated, only increased oxygen tension, immobility, and dietary factors are well known to influence the red blood cell. Dietary considerations may be important, but at this time there are no clear indications that the flight diet had deleterious effects. Although immobility reduces red cell mass by curtailing erythrocyte production, flight observations suggest that hemolysis may also be significant. It is possible, although not demonstrated by any previous studies, that weightlessness per se is a contributing factor in the hemolysis observed. Altered hemodynamics, resulting in hemostasis, could inflict a pre-lytic lesion on the erythrocytes involved and thereby result in the cell's premature demise. Some workers have found significant reduction in hematologic and neurologic toxicity in animals exposed to high pO_2 when an inert gas is present. Therefore, the absence of an inert atmospheric diluent (nitrogen) could be significant at the hyperoxic levels encountered within the Gemini spacecraft. Of these mechanisms, the conditions dictated by the spacecraft environment give some credence to oxygen as the possible hemolytic agent.

(5) Biochemistry. Analysis of urine and plasma was used as an indication of the astronauts' physiological status before, during, and after flight. Analyses of the results obtained on two or more of these phases were performed for several Gemini flights but the number of observations has not been adequate to establish variabilities and trends.

(6) Gastrointestinal System. Functioning of the gastrointestinal tract has been normal on all missions and no evidence exists for excess nutrient losses due to poor digestibility of food during flight. Menus were made up of approximately 50 to 60% rehydratables, requiring the addition of water prior to ingestion, and bite-sized items that are rehydrated in the mouth. About 50% of both the rehydratable and bite-sized foods are freeze-dried products; the remaining are other types of dried or low-moisture foods, some of which are compressed. A typical menu has an approximate calorie distribution of 17% protein, 32% fat and 51% carbohydrate. Total calories provided and eaten per day have varied from flight to flight. Although weight loss occurred on all missions, it did not appear to increase with mission duration.

(7) Genito-Urinary System. There have been no difficulties involving this system. Urination has occurred normally both inflight and postflight, and there has been no evidence of renal calculi.

(8) Musculo-Skeletal System. The information gathered to date on bone and muscle metabolism as affected by space flight is limited to a very few subjects under varying dietary intakes and exposed to multiple flight stresses. A comparison of bone-density changes at several anatomical sites for the crews of three Gemini missions is shown in Table 9-1.

TABLE 9-1
Comparison of Bone-Density Changes in Gemini Astronauts During Space Flight

Position of anatomical site evaluated	Change in bone mass ^a (percent)	
	Command Pilot	Pilot
Conventional os calcis scan:		
Gemini 4 (4-day flight)	-7.80	-10.27
Gemini 5 (8-day flight)	-15.10	-8.90
Gemini 7 (14-day flight)	-2.91	-2.84
Multiple os calcis scans:		
Gemini 4	-6.82	-9.25
Gemini 5	-10.31	-8.90
Gemini 7	-2.46	-2.54
Hand phalanx 5-2 scans:		
Gemini 4	-11.85	-6.24
Gemini 5	-23.20	-16.97
Gemini 7	-6.78	-7.83
Hand phalanx 4-2 scans:		
Gemini 4	(b)	(b)
Gemini 5	-9.98	-11.37
Gemini 7	-6.55	-3.82

a Based on x-ray absorbancy of calibration wedge.

b Not done on this flight.

Table 9-2 compares bone-density changes in the 14-day Gemini 7 mission (1965-100A) with bed-rest subjects on similar diets for an equal time. From a tentative evaluation of food intake based on the residue removed from the spacecraft postflight, it was estimated that 1.00 g of calcium was consumed by the Gemini 7 crewmen during their orbital flight. On this basis, the os calcis and hand phalanx 5-2 were compared with subjects at supine bedrest for 14 days in bedrest units. Bedrest men on comparable diets lost slightly more in the os calcis and considerably less in phalanx 5-2 than did the crewmen on this mission. Activities of the Gemini 7 flight crew were calculated in part to support a metabolic study. Hence, tasks not related

TABLE 9-2

Comparison of Bone-Density Changes in the Gemini 7 Crew With Bedrest Subjects on Similar Diets for 14 Days

	Gemini 7 Crew		Bedrest Subjects
	Command Pilot	Pilot Pilot	
Mean calcium daily intake (estimated), grams	1.00	1.00	(1) 0.931 (2) 1.021 (3) 1.034 (4) 1.020 (5) 0.930
Change in conventional section of os calcis in bone mass (calibration wedge equivalency), percent	-2.91	-2.84	(1) -3.46 (2) -3.56 (3) -5.79 (4) -5.11 (5) -5.86
Change in bone mass of hand phalanx 5-2, percent	-6.78	-7.83	(1) -1.57 (2) -1.00 (3) -0.44 (4) -0.96 (5) -1.27

to this objective were minimized, so that time could be spent on isometric and isotonic exercise, on exercise with a mechanical device, and in sleeping. Also there was more time available for eating. By consuming a larger proportion of the diet provided, the crewmen not only increased the amount of calcium that they consumed, but also the quantity of total energy and of other essential nutrients. Furthermore, various foods supplied for this mission were provided with supplementary calcium.

The results of the study show decreased loss of x-ray density of the largest bone in the foot (os calcis), but with far less dramatic results obtained with the hand (phalanx 4-2). This would indicate the need for further attention to the development of exercise routines which would involve the hands and fingers. Without reducing the emphasis on dietary calcium, a probable need exists for further research on other nutrients known to be related to skeletal status that might prove to be important variables.

The overall conclusions are as follows: Observations on the physiological effects of space flight on man have shown significant changes involving only the cardiovascular, hematopoietic and musculo-skeletal systems. Even these changes appear to be adaptive in nature and are measured principally during the readaptive phase to the 1-g environment. Confidence in these results will be improved as more information is gained on future flights. However, it must be remembered that these are gross findings and much must yet be done in the laboratory and in flight to understand more fully the mechanisms involved. (More detailed discussions of

Gemini results may be found in the proceedings of The Gemini Midprogram Conference (NASA SP-121, 1966). See also Section 12 of the Bibliography for references to other works.)

Gemini Radiation Measurements. Radiation monitoring with nuclear emulsion packs worn by the astronauts in their space suits was carried out on all Gemini flights. The highest doses were recorded on the 14-day Gemini 7 mission (230 mrad), and on Gemini 9 which involved an excursion to 752-km altitude in the South Atlantic magnetic anomaly (1.02 rad). Track and grain count analysis of G.5/K.2 emulsion pairs revealed that more than 90% of the absorbed dose was due to protons in the 0-to-300 MeV energy range, apparently picked up in passes through the anomaly. Even within the indicated energy interval, the dose contributions, per MeV, center heavily on low energies, with 40% of the total dose due to protons of $E < 20$ MeV and 20% due to protons of $E < 10$ MeV. The softness of the radiation is further demonstrated by large variations of the local dose at different positions on the astronauts' bodies (factor of 2) and even at different spots on the same film sheet of $1 \times 1\frac{1}{2}$ in. size (factor of 1.35). The results indicate that in near-Earth orbits the proton exposure in the South Atlantic anomaly is the predominant source of radiation exposure, and that the radiation level within the ship varies greatly, not only over distances comparable to body size but even on the cm-scale, reflecting the complex local shielding geometry. These experiments were conducted by the Naval Aerospace Medical Institute, Pensacola.

Gemini Vestibular Experiment. Background studies centering on the influence of cues from the gravito-inertial force environment on the visually perceived direction of space suggested the vestibular experiment carried out in the Gemini 5 and 7 flights. The astronauts' task was to set a luminous line of light to the horizontal of the spacecraft in flight and to set it to the Earth-horizontal while in the upright position pre- and postflight. These studies confirmed the fact that (1) under natural living conditions the most important cues for the perceived direction of space are furnished by vision and by sensory receptor systems stimulated directly or indirectly by gravito-inertial force environment; (2) the best concordance between the two is manifested with the subject upright, and (3) that with tilt away from the upright the well-known E- and A-phenomena appeared. The experiment was designed and conducted by the Naval Aerospace Medical Institute, Pensacola.

2. BIOSATELLITE PROGRAM

The first in a series of biological satellites, Biosatellite 1 (1966-114A), was launched by NASA from Cape Kennedy, December 14, 1966. Its initial perigee was 256 km; apogee, 286 km; inclination, 33.5° ; and period, 91 min. A programmed sequence to initiate the de-orbit maneuver of the experimental capsule was begun on December 17, but retrofire did not occur and the capsule was not recovered.

The objective of the Biosatellite program is to determine the effects of the space environment on various life processes. The 13 experiments carried on Biosatellite 1 were designed to study the effects of weightlessness on the life processes of certain organisms and the effects of radiation on organisms in weightlessness. It was planned to return the experimental capsule to Earth after three days in orbit.

To evaluate the genetic effects of radiation under weightlessness, the biologists planned to determine the frequencies of chromosome breakage and the frequencies of mutation at many different genetic loci. Basic mechanisms to be studied by the non-irradiated experiments included: cell division, synchrony and orientation of cell division; alteration in division and growth in cells of a developing embryo; effects on the basic structure of protoplasm; effects on enzymes; and orientation to gravity of leaves, roots, and shoots of various plants. All biological materials were to be examined upon return for growth, changes in shape, changes in structure of tissue and cells, and for biochemical changes. The experimenters planned to use light microscopes and electron microscopes, chromatography, and many other analytical techniques. All 13 experiments had identical control versions on the ground, subjected to conditions close to those of the flight experiments, except for weightlessness. The radiation experiments also had non-irradiated replicas aboard the spacecraft. These experiments were to supply further data on the effects of weightlessness alone.

A second Biosatellite containing the same experiments is planned for launch in mid-1967.

Satellite Tracking, Geodesy, Navigation, Terrain Photography, and Earth Resources Survey

1. TRACKING

Deep Space Network. During 1966 the Goldstone 210-ft diameter antenna system (Figure 10-1) became an operational facility of the NASA Deep Space Network. The communication performance characteristics of the advanced system compared with the present 85-ft antenna systems of the DSN are:

	85-ft	210-ft
Antenna Gain - dB		
Receive (2290-2300 MHz)	53.3	61.8
Transmit (2110-2120 MHz)	51.3	60.
System Noise Temperature		
(10 KW Diplexed Mode)	55°K	45°K

The increased capability of the 210-ft antenna has extended the communication range of the DSN, providing support for the entire useful trajectory of the Pioneer 6 (1965-1968). This extended range was further demonstrated on May 3, 1966, by re-acquiring telemetry data from Mariner 4 through the spacecraft's omnidirectional antenna at a distance of 320 million km.

Optical Tracking, Smithsonian Astrophysical Observatory. During 1966, the SAO network of Baker-Nunn cameras made the following observations of artificial earth satellites (Satellites observed less than 25 times have been omitted).

An accurate method of determining satellite and deep-space probe positions is by referring them to the background stars. When using this technique it is necessary to make the reference



Figure 10-1. Goldstone 210-ft diameter antenna system located in California's Mojave Desert. The antenna forms part of the NASA Deep Space Network (NASA-JPL).

BAKER-NUNN OBSERVATIONS 1966

Satellite	No. of Observations	Satellite	No. of Observations
1958 Alpha 1	1169	1964-5A	137
1959 Alpha 1	2011	1964-63C	180
1959 Eta 1	1865	1964-63E	298
		1964-64A	1045
		1964-76A	1896
1960 Eta 1	882		
1960 Iota 1	4295	1965-9A	132
1960 Iota 2	2935	1965-14A	26
1960 Nu 1	1898	1965-32A	2227
1960 Xi 1	2099	1965-34C	3667
		1965-63A	1481
1961 α Delta 1	5013	1965-78A	2333
		1965-81A	1460
1962 β Alpha 1	249	1965-89A	7967
1962 β Mu 1	1803	1965-98A	800
1962 β Tau 2	1632	1965-16A	75
1962 β Psi 1	435		
		1966-5A	1132
1963-24A	699	1966-19A	178
1963-25B	72	1966-31A	187
1963-26A	1325	1966-31C	99
1963-30A	2698	1966-44A	707
1963-30D	3430	1966-56A	3725
1963-49B	273	1966-56B	156
1963-53A	2779	1966-56C	35
1963-53B	84	1966-56D	60
		1966-89B	66
1964-1A	324	1966-99B	33
1964-4A	1801		
Total observations: 69,873			

measurements on stars of about the same brightness as the space probe. Unfortunately, the standard of astronomical reference system (FK4) hardly extends to stars fainter than the sixth visual magnitude. SAO has attempted to extend the FK4 system to stars as faint as the 10th visual magnitude uniformly distributed over the entire sky.

Laser Tracking. A laser satellite-tracking system was operated continuously during 1966 at the SAO astrophysical observing station at Las Cruces, New Mexico. During the year a total of 1192 range measurements were made on Explorer 22 (or Beacon B, 1964-64A), Explorer 27 (or Beacon C, 1965-32A), and GEOS A (or Explorer 29, 1965-89A), each equipped with a retroreflector. The accuracy of the laser range-measuring equipment is within a few meters. GEOS orbits for early 1966 were computed using precisely reduced Baker-Nunn observations together with laser observations for the same period. The residuals of the laser range measurements were consistent with the residuals of the angle measurements from the cameras. A new prototype laser system was designed for completion in 1967.

Echoes were also obtained from Explorer 22 at ranges between 1070 and 1840 km with a ruby-laser radar system mounted upon a modified Nike-Ajax radar adjacent to and slaved to the Millstone L-band radar at MIT's Lincoln Laboratory. By observing a number of Echo 1 and 2 (1960 Iota 1 and 1964-4A) tracks on a boresight monitor, it was possible to determine a set of elevation corrections and to demonstrate the feasibility of using the angular data from the L-band tracking radar to maintain angular tracking of the narrow beam (about 2 mrad) of the laser-radar system. The laser generated a peak power of 250 megawatts in 5 joule pulses 20 nsec in length at a rate of one pulse/sec. The receiver optics used a 10-in. telescope and a red-sensitive photomultiplier.

At AFCRL, laser-geodesy experimentation has continued to center around pulsed ruby-lasers; however, echo testing emphasizing normal pulsing techniques has had to share emphasis with the development of a new technique which has evolved from experimentation by AFCRL on improved cooling and triggering. This new laser employs a Kerr cell Q-switch to control its firing. It has been found possible to program the laser with several giant pulses at precisely timed intervals during a single pumping period. A theoretical study of such a laser has been completed and exploratory measurements have been made with a breadboard unit on ground targets. These early measurements are currently limited by data-reading resolution and lack of precise timing of the pulse programming circuitry.

Comparison of Results. One of the objectives of the GEOS A mission was to conduct systematic comparisons of the various operational and experimental tracking systems. In 1966, large scale, systematic side-by-side comparisons involving a majority of the existing geodetic tracking systems were obtained for the first time by the Goddard Space Flight Center. Comparisons have been made between various types of camera data, the SECOR electronic ranging system of the Department of Defense, and the Range and Range Rate tracking system of NASA. These initial comparisons indicated no serious discrepancies among the various tracking systems. The agreement found among them gives added confidence in the accuracy of all the systems. As the analysis of the data taken during 1966 continues, improved calibrations and detection of small systematic errors should allow even greater improvement in the accuracy of each of the tracking systems. As a by-product of these comparison studies, improved calibrations have been obtained for the NASA Range and Range Rate system and the Minitrack Optical Tracking System cameras.

Celestial Mechanics. Radar tracking of the Lunar Orbiter has been shown by Anderson at JPL to be useful in making indirect measurements of the geocentric orbit of the Moon's center of mass. The planned series of lunar orbiters will permit such observations to be extended over a period of two years. Thus refinements of the ephemeris of the Moon would seem a likely result of this series. Anderson has also made a broad survey of techniques used to determine the trajectories of artificial celestial bodies from optical and radar observations (American Astronautical Society, Sci. & Tech. Series 9, 133, 1966). Included are discussions of orbit computation methods, representation of data, and the differential correction of orbits. The application of the differential correction process to the determination of astronomical constants and ephemerides is explained and it is concluded that radar tracking of spacecraft adds an important new tool to the field of observational astronomy.

Demise of the West Ford Dipoles. Radar measurements at Lincoln Laboratory have confirmed that the several hundred million individually orbiting West Ford dipoles, placed in orbit

May 1963, have re-entered the lower atmosphere in accord with Shapiro's predictions. Calculations indicate that these tiny copper wires should have survived re-entry and floated gently back to Earth; however, the probability of finding one is miniscule. Some dipole clusters from the first experiment, where proper separation was not achieved, still remain in orbit but almost all of these should return to Earth within the next two years.

2. SATELLITE GEODESY (DYNAMIC AND GEOMETRIC)

At the beginning of 1966, the first three spacecraft of the NASA geodetic satellites program were in orbit. Explorers 22 and 27 continued to provide useful Doppler and laser tracking data throughout the year. GEOS A (or Explorer 29), launched in November 1965, was just beginning its anticipated one-year active lifetime. In addition, several satellites not launched specifically for geodesy continued to be used for geodetic purposes: Echos 1 and 2 for geometric satellite geodesy and numerous others for gravimetric analyses.

All systems on GEOS A remained fully operational until December 1, 1966, when the main command unit malfunctioned, terminating a large part of the geodetic observation capability (Doppler, Range and Range Rate, and the flashing light). At the end of 1966, data continued to be gathered from the remaining tracking systems (SECOR electronic ranging and laser ranging). During the period from November 1965 through November 1966, world-wide tracking data were obtained from some 110 tracking stations. The flashing lights on GEOS A were photographed more than 20,000 times during this period. This satellite and PAGEOS (1966-56A) gave many observers from different nations an opportunity to collaborate in investigations based on tracking data. Optical and electronic data, reduced and processed, are now archived in the Geodetic Satellites Data Service at Goddard Space Flight Center, where they are made available, on request, to scientific investigators. As the data were being obtained, analytical techniques and programs for data analyses were being developed and programmed. By the end of 1966 these were largely operational.

The 30-m passive balloon satellite, PAGEOS, was successfully launched into a nearly circular, approximately 4250-km altitude orbit in June 1966, primarily in support of the world-wide geodetic tracking network. At the end of 1966, NASA, SAO, and USC&GS cameras were actively observing PAGEOS from a large number of stations. Plans are under way to carry out a vigorous observational plan using PAGEOS to allow by the end of 1967 the acquisition of sufficient data to establish an interim geometric reference network. Launch of GEOS B into a 1500 by 1100 km orbit, inclined 70° , in late 1967 or early 1968 is anticipated.

As a result of these and other activities, the year 1966 has seen considerable improvement and refinement of the gravimetric field obtained from satellites, resulting in a gravimetric field definition which is now, NASA believes, in essential agreement with available surface data for components of the gravity field having wavelengths of approximately 2000 km or greater. Certain of the more detailed components of the gravity field which have significant effects on the motions of close Earth satellites have also been identified. For example, observations of GEOS A have made it possible to calculate definition of the 12,12 spherical harmonic, a component of the gravitational field having a wavelength of about 1500 km.

The Naval Weapons Laboratory performed routine orbit computations for GEOS A and a polar orbiting satellite, based on Doppler data from 13 sites. Doppler observations made

on these satellites by equipment in mobile vans were used to position isolated sites periodically. An extensive amount of data has been processed in a computer program which will yield over 200 coefficients in the expansion for the Earth's gravitational potential including all terms through 12th degree and order, and various additional terms to 19th degree.

At SAO, satellite-tracking data from Baker-Nunn photographs, laser ranging, and other techniques produced further geodetic results. From long term observation of three satellites (1959 Alpha 1, 1959 Eta, and 1960 Iota 2), the orbit perturbation caused by deformation of the Earth due to the gravitational pull of the Moon and Sun has been detected. From the amplitude of the observed perturbation, Kozai has derived a value for Love's number of $k_2 = 0.39 \pm 0.05$.

A signal accomplishment of the past year was the successful blending of various types of data—optical, radio, etc.—in calculating highly accurate orbits for scientific objectives. This diversification of the data base lends confidence to the geopotential and the geometrical positions derived from satellite tracking data. GEOS A provided a particularly valuable vehicle for resolving certain systematic problems involved in combining diverse tracking data. SAO is a party to collaborative agreements under which positions of many tracking stations have been determined relative to the standard coordinates for the Baker-Nunn sites published in *Space Research VII*. The data from these added sites are also valuable in improved determinations of the geopotential.

USAF efforts in satellite geodesy with active satellites consist of photographic observations of high-intensity lights carried on the satellites ANNA-1B (1962 Beta Mu 1) and GEOS A and flashed by ground command. These optical beacons are photographed against star backgrounds to determine distance and direction between widely spaced camera sites and to learn more about orbital dynamics and the forces acting on satellites. At the latest count (May 1, 1966), USAF observations on ANNA-1B had produced 1104 plates with flash images. Although GEOS A experienced a malfunction of its lights on December 1, 1966, it had by that time yielded 773 image plates since its launch on November 6, 1965. The Aeronautical Chart and Information Center reduces the camera-plate data and computes geodetic positions and azimuths therefrom. The Military Airlift Command's 1381st Geodetic Survey Squadron performs the camera observations.

Passive satellites, whether sunlit like Echo and PAGEOS, or ground illuminated like the reflector-bearing Beacon Explorers 22 and 27, are becoming increasingly important in the Air Force program in satellite geodesy. One technique using passive satellites consists of making timed interruptions of the traces of Sun-illuminated satellites as they cross the field of view of long focal length stellar cameras. These interrupted traces, collected simultaneously by several cameras equipped with high speed shutters yield data that can be used to make geodetic position and azimuth computations, similar to the active satellite methods. Experimentation has progressed beyond the three-station test reported by AFCRL last year to an intercontinental effort now in progress which involves USAF cameras at Bedford, Massachusetts; Torrejon, Spain; Aberdeen, Maryland; Kindley, Bermuda; Grand Forks, North Dakota; and Savannah, Georgia.

AFCRL scientists have been making a detailed study of the spherical harmonic coefficients obtained from various satellite-orbit solutions, comparing them with one another and with the coefficients obtained from direct gravity measurement. Their conclusions, which seem to be somewhat more pessimistic than those of NASA, are as follows: (1) Using orbital analyses methods, the second, third, and fourth degree zonal harmonics have been determined with reasonable accuracies. Higher order zonal and all tesseral harmonics are considered

doubtful at the present time; (2) The agreement between the various sets of coefficients is better if the corresponding geoids are compared. However, discrepancies of up to 20 to 30 m occur between "best" solutions. The anomalies, like the geoid undulations, reveal the inconsistencies between various solutions unless mean values for $30^\circ \times 30^\circ$ areas were used; (3) The very strongly correlated coefficients obtained from orbital analysis represent the smoothed gravitational field at an average satellite altitude and cannot be used at or near the Earth's surface without qualifications because of the inverse attenuation effect; (4) The largest error source in the satellite coefficients is the effect of the higher harmonics which are set equal to zero. In addition, the error caused by the density and distribution of observations is substantial (aliasing and window effect); (5) Statistical considerations have an undesirably large influence and the systems of equations for tesseral harmonics are always ill-conditioned; (6) The spherical harmonics determined from present-day surface gravity are also inadequate. The main problem here is the effect of large gaps in the gravity coverage. These gaps cause large systematic distortions, ill-conditioned equations and correlations which cannot be eliminated by statistical manipulations; (7) A decisive improvement of the present-day situation is possible by filling in the gaps by airborne gravity profiles thereby making the gravity coverage really uniform. Then, the individual harmonic coefficients can be determined independently, i.e., each coefficient is obtained by itself in one integration. Statistically, this independent determination results in zero correlation between coefficients, which is of considerable value. If only two symmetrically located gravity profiles were to be measured in each $5^\circ \times 5^\circ$ block in the empty areas, the harmonic coefficients up to order 30 could be computed with sufficient accuracy for all geodetic and satellite dynamic purposes.

The past year has seen the beginning of a concerted effort by the University of Hawaii to examine in detail, using surface geophysical methods, one of the anomalous gravity areas revealed by the satellites, thus demonstrating the impact of satellite geodesy on more conventional geophysical work.

Satellite Navigation System. The U.S. Navy's all-weather satellite navigation system has been in operational use since July 1964. Satellites transmit orbital information and constant-frequency carriers so that a shipboard Doppler receiver and computer can obtain an accurate position fix of a ship at the time of a satellite pass above the ship's horizon. The system is available for use by research vessels in oceanography and geophysics. A study by Guier of APL (J. Geophys. Res. 71, 5903, 1966) presents a brief review of the navigation system, a theoretical description of the satellite Doppler data received, and a simplified description of the computations required to obtain a navigation fix. Emphasis is placed upon the AN/SRN-9 integral Doppler equipment. This equipment has been designed especially for use by surface ships where cost, weight, and power requirements are important considerations. Similar equipments have been undergoing sea trials to determine their applicability for research vessels if a post-analysis capability for determining ship's position is a critical requirement. The results have amply demonstrated the potential usefulness of the AN/SRN-9 for oceanography.

3. TERRAIN PHOTOGRAPHY AND EARTH RESOURCES SURVEY

The objective of the NASA Earth resources survey program is to determine the natural and cultural resource data which can best be acquired from space for the economic benefit of the

nation and mankind. The remote sensing capabilities demonstrated by meteorological satellites and the recent Gemini flights have indicated the potential of satellites for surveys of Earth resources. These early satellite results, and investigations employing aircraft, have demonstrated that satellites can provide useful data in agriculture and forestry; geography, cartography and cultural resources; geology and mineral resources; hydrology and water resources; and oceanography and marine resources.

Several hundred color photographs of land and near-shore oceanic areas have been taken during Gemini flights as part of the Synoptic Terrain Photography Experiment (S-5). The objective of the S-5 experiment was to obtain small-scale high-quality color photographs of the Earth's surface for geologic, geographic, and oceanographic study. Equipment included hand-held Hasselblad and Maurer cameras with 80-mm lenses, haze filters, and 70-mm color and color infrared film. (See also last year's report to COSPAR.)

Substantial geologic and topographic detail is evident in the Gemini pictures. Different types of rocks can be readily distinguished from each other by color and topographic expression, although positive identification and classification of the rocks are not possible from the pictures alone. A further advantage of satellite observations is that many large-scale features are revealed that are not apparent on smaller-area photographs. For example, the examination of a Gemini photograph of Iran shows a large scissors fault of recent origin cutting across sedimentary rock strata folded into complex anticlinal and synclinal mountain ranges. This major fault is oriented approximately north-south and extends more than 100 km as shown to the right of center in Figure 10-2. This photograph shows the relationship of the fault to the regional geologic structure, which is not possible with aerial photomosaics. Delineating the rocks into gross units may save time and expense in planning geologic projects.

The experiment has demonstrated the geologic usefulness of hyperaltitude color photography. The pictures have revealed substantial inaccuracies and omissions in geologic maps. In addition, they indicate the potential application of hyperaltitude photography to geologic problems such as continental drift, the relation of volcanism to regional tectonics, the formation of regional sand-dune fields, the formation of pediments, and the origin of red beds.

The television pictures from the advanced vidicon cameras on the Nimbus satellites have also provided data for use in geologic analysis. Figure 10-3 is a Nimbus photograph of the Columbia River Basin of the United States. In the upper right portion of the figure the dark irregular lines are drainage channels resulting from the blockage of the Columbia River by the continental ice sheet during the last Ice Age. The lighter gray shading outlines soil-covered areas and the dark gray shading shows areas of volcanic bedrock where the soil had been removed by steam erosion. This photograph provided verification of the theory that the Columbia River had been blocked and overflowed the higher elevations; the basis of the theory had been an intensive investigation conducted over a 20-year period. Nimbus visual and infrared data have been used also to map the major ocean currents such as the Gulf Stream and to chart ice boundaries around Antarctica and Greenland. This information could be of economic importance to the fishing and shipping industries of the world.

Remote sensing from aircraft using infrared techniques has indicated several potential space applications of benefit in hydrology, agriculture, forestry, and oceanography. The adaptation of this technique to space vehicles offers a means of repetitively surveying large areas to measure the extent of resources such as agricultural crops and forests, detect the onset of disease, and assess the extent of the damage. Aerial infrared imagery has also been used to

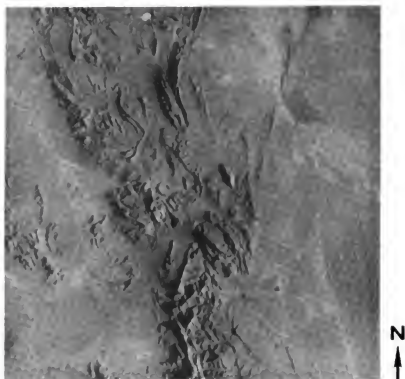


Figure 10-2. Gemini 5 photograph of a large scissoring fault in the Dasht-i-Lut Desert in Iran, taken on August 26, 1965, at an altitude of approximately 203 km (NASA).

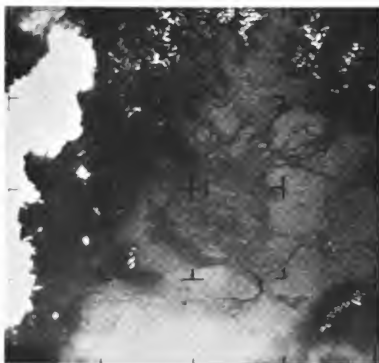


Figure 10-3. Nimbus 1 AVCS photograph of geologic features in the Columbia River Basin, taken September 5, 1964 (NASA).

detect the subsurface outflow of cold fresh water into the ocean around islands and to chart the dispersion of pollutants into rivers, bays, and lakes.

The analyses of satellite data have demonstrated that this technique can have important practical applications in the Earth resources survey program. Additional studies and investigations will be conducted in 1967, and experiments specifically designed to collect Earth resource data are planned for future automated and manned space flights.

PART III

Related Space-Vehicle Technology

Related Space-Vehicle Technology

1. COMMUNICATIONS AND APPLICATIONS TECHNOLOGY SATELLITES

The following is a brief account of the status and accomplishments of U.S. communications and applications technology satellites in 1966; plans for launches in the near future are summarized.

National Aeronautics and Space Administration. Relay 2 (1964-3A) and Telstar 2 (1963-13A) are still in operable condition after three and three and a half years in space, respectively. Relay 2 was used very seldom in 1966 for communications experiments and then principally by foreign ground stations. Extensive data were obtained throughout the year from the two charged-particle experiments on board the satellite. Telstar was not operated during 1966.

Echo 1 (1960 Iota 1) and 2 (1964-04A) continue to be used for geodetic measurements and air-drag studies. No government-supported communications experiments were conducted with them in 1966 nor are any such experiments planned for the future.

Both Syncom 2 (1963-31A) and 3 (1964-47A) continued to carry operational traffic in the Indian Ocean and Pacific areas throughout 1966. Syncom 2, which exhausted its station-keeping propellant in 1965 oscillates around the 73°E meridian and Syncom 3, which exhausted most of its propellant in July 1966, is currently drifting slowly westward from 160°E longitude.

NASA launched its first Applications Technology Satellite, ATS-1 (1966-110A) on December 6, 1966, placing it in geostationary orbit over the equator at 151°W longitude on December 16, 1966. The spacecraft is producing the designed prime power of 185 w from its 22,000 solar cells. It carries a variety of scientific and engineering experiments, among them a VHF-FM repeater translator that will enable an experiment to provide voice communications between a ground station and airplanes in flight. Experiments are also planned to utilize the 600-channel duplex repeater capability which receives single sideband (SSB) signals in the 6-GHz frequency range and converts the SSB into phase modulation in the 4-GHz cycle frequency band for the down link, thus permitting multiple-access experiments. The spacecraft's communications systems utilize a unique electronically-despun phased-array antenna system that keeps the antenna beam pointed at the Earth even though the spacecraft body is spinning. Two damage

experiments are carried on the satellite to measure directly the synergistic effect of electromagnetic and particulate radiations on several kinds of solar cells having varying degrees of protection and on thermal-control coatings of various types. Other scientific experiments carried on ATS-1 are described in the appropriate chapters in Part II.

On April 6, 1967, NASA launched its second Applications Technology Satellite ATS-2 (1967-31A) into an 11,000-km circular, inclined orbit. This satellite is three-axis gravity-gradient stabilized and carries in addition to other technology experiments, a meteorological camera experiment similar to Nimbus, charged-particle detectors, an Earth-albedo sensor, damage experiments, a VLF whistler detector, an electric-field detector, and a solar-radio-burst receiver.

Department of Defense. On June 16, 1966, the DOD launched the Early Gravity-Gradient Test Satellite, GGTS-1 (1966-53A), into a near geostationary orbit in conjunction with its first group of Interim Defense Communication Satellites (IDCSP). Development of this relatively simple two-axis gravity-gradient experimental satellite was supported by NASA. Performance of the stabilization system was nearly normal except for a cross-plane bias of about 15° that is probably caused by adherence of a small (0.010-to-0.030 in.) magnetic particle to one of the magnetically-anchored dampers designed to reduce libration.

A scheme allowing computation of the angular orientation of a satellite was proven by an experiment aboard one of OAR's OV 7 (Satar) spacecraft. Simultaneous measurements of three components of the magnetic field, two Sun reference angles, and time are stored by sample and hold circuits for commutator readout. Digital manipulation of the recovered data yields the desired angles so that the on-board sensor orientation with respect to the velocity solar or magnetic field vectors may be determined.

Communications Satellite Corporation (COMSAT). Early Bird 1 (1965-28A) continued to operate satisfactorily throughout 1966, routinely carrying commercial communications, including television, across the Atlantic Ocean. On October 26, 1966, a larger commercial communications satellite, the first Intelsat 2 (1966-96A), was launched for COMSAT by NASA; however, failure of the apogee motor immediately after ignition prevented attainment of the desired geostationary orbit over the Pacific Ocean. It is currently in an elliptical, inclined orbit with apogee at about 36,800 km and perigee of 3330 km, each occurring over the equator. In this orbit some communications usage is possible and the satellite is normally used for commercial traffic from Hawaii to the mainland about 5 to 7 hr/day. The second Intelsat 2 (1967-1A) was successfully launched on January 11, 1967 and is in commercial service in geostationary orbit over the Pacific Ocean. An additional Intelsat 2 satellite is scheduled for launch in 1967.

2. DEVELOPMENTS IN SOUNDING-ROCKET TECHNOLOGY

NASA is obtaining a solid fuel, single stage, sounding-rocket system that will lift a 50-lb payload to 100 km for conducting experiments in the D region of the ionosphere. This system should be operational by late 1967. NASA is also supporting the development of a solid fuel, single stage, sounding-rocket system that will lift a 50-lb payload to 200 km and a 100-lb payload to 100 km.

The second successful test flight in 1966 of a large, new, liquid-fueled rocket system capable of lifting a 500-lb payload to an altitude of 352 km has been reported by NASA. The system is now operational from Wallops Island; operational capability from White Sands, where payload recovery will be possible, should be available by 1968.

NASA has also developed a stellar pointing control system for sounding rockets, which consists of a standard inertial attitude control system and a fine-error sensing system that has a jitter accuracy of ± 20 arc sec and can discriminate between stars differing by as little as one visual magnitude. This system was developed at GSFC and has been successfully flown on several rockets. A three-axis solar pointing control system is also being developed to point a separated payload at the Sun with a jitter accuracy of ± 5 arc sec. The first flight of this system is scheduled for late 1967.

The family of sounding rockets used by AFCRL changed only in engineering detail during 1966. Basic studies of the dynamics of rockets continued, and a new method was developed to determine the stability of a long, slender rocket body with regard to coupling of the rigid-body aerodynamic pitching frequency and the lowest natural body bending frequency. A transportable launch facility was constructed and used in Puerto Rico.

The problem of accurately determining the position of a sounding rocket launched out of range of radar stations continues. A Doppler technique using an extremely stable rocket-borne transmitter was tested and proven. The transmitter can also be the main rf link to carry the prime experimental data, thus simplifying the payload and reducing its weight.

3. DEVELOPMENTS IN BALLOON TECHNOLOGY

During the past 18 months the reliability of polyethylene plastic balloons has increased measurably through the use of co-polymetric materials and new polyethylene resins at AFCRL. These balloons carrying payloads up to 1 ton have been extensively used with more than 90% success. There has also been increasing need of heavier payload flights for which the unreinforced polyethylene balloon is not suitable. Families of reinforced films, principally Mylar film with Dacron fibers in various thicknesses and deniers, have been developed to provide balloons of nearly 100% reliability for these heavy, and generally more expensive, payloads. The AFCRL flying-thread loom, discussed in previous COSPAR reports, has made the fabrication of these improved materials possible.

In 1966, AFCRL developed the world's largest balloon of 26-million ft³ volume. Designed for the NASA Voyager program, the balloon, constructed of flying-thread-loom material, placed a 1-ton capsule over a specified area at an altitude of 130,000 ft. The experiment, involving rocket acceleration of the capsule, was to provide a full-scale evaluation of parachute systems to be used in the 1972 soft-landing of the Voyager instrumentation on Mars. The balloon cost \$100,000. The use of previously available reinforced materials would involve an estimated cost of \$300,000 for a balloon of 84-million ft³ volume.

Other AFCRL balloon programs included the flight of a 10,000-lb instrumentation payload to 65,000-ft altitude for two days and development of an inexpensive system for tethering 300 lb at 10,000-ft altitude for periods of 12 hr. Both programs involved extensive meteorological and climatological studies, launching system design, and design of special balloon vehicles. Both programs were successful.

AFCRL uses modular instrumentation, specifically tailored to meet the requirements of each flight, for measurement and control of balloon performance, for flight safety, and for accurate programming, encoding, and transmission of data measured by sensors carried aloft by the balloon. A communications relay and a command data link have recently been added to the AFCRL modular inventory. The balloon-borne UHF relay enables line-of-sight communications from the balloon control center, through the balloon, to vehicles or aircraft that may be as far as 800 mi from the launch site. The data link consists of a UHF transmitter-receiver that will relay control commands from the ground to any point on the balloon system. Functions such as valving at the apex of the balloon (which may be as far as 800 ft above the main flight instrumentation) or the control of experiments deployed several thousand feet below the balloon can be performed without adding long and cumbersome wire circuits.

Precision ballooning, the ability to position a balloon over a specified target area at a desired time, has become an important adjunct to the capabilities of the constant-level balloon in support of scientific research programs. A study of flights conducted throughout the year at White Sands Missile Range showed that the use of sophisticated electronic command packages in conjunction with precision wind-forecasting techniques has resulted in 50% of the flights being within 5 mi of the target center and within 5 min of the scheduled time.

PART IV

**Ground-Based and Theoretical
Space Research in 1966**

Particles and Magnetic Fields near the Earth and in Interplanetary Space

This chapter contains reports on researches made primarily with ground-based facilities, and theoretical or interpretive studies of the properties and behavior of charged particles and fields in the interplanetary medium, magnetosphere, and at the Earth.

1. THE INTERPLANETARY MEDIUM

Cosmic-Ray Propagation. Jokipii at the University of Chicago has conducted a theoretical study of charged-particle motion in an irregular magnetic field. The magnetic field is taken to be the superposition of a constant vector field B_0 (taken for convenience to be the Z direction) and a smaller fluctuating component B_1 which is a homogeneous random function of position with zero mean. The Fokker-Planck coefficients, describing the evolution of the particle distribution in pitch angle and position, are derived explicitly in terms of the two-point correlation function of B_1 , or alternatively, in terms of the Fourier spectrum of the irregular field. The time evolution of the distribution is found to depend on the irregular field in two ways: (1) A particle is scattered by those irregularities that are seen by the particle to be in resonance with its cyclotron frequency, and (2) A particle follows the random walk of a field line in the XY-plane as it moves along the Z-axis. The diffusion limit of the Fokker-Planck equation, suppressing the pitch-angle dependence, is then considered and a diffusion tensor is derived. The theoretical work is applied to spacecraft magnetic-field observations, and the Fokker-Planck coefficients are related to the observed power spectrum of interplanetary magnetic-field fluctuations.

Also at Chicago, Parker has studied the effect of adiabatic deceleration on the cosmic-ray spectrum in the solar system. Cosmic rays in the magnetic fields carried in the solar wind are continually spread out and decelerated, in addition to being convected out of the solar system. The effect of the deceleration on the cosmic-ray spectrum is calculated for the case in which the outward convection of cosmic rays is small and for the case in which the cosmic-ray spectrum is a simple power law and the diffusion coefficient is independent of energy. The calculations are carried out for both particle momentum and energy. It is shown

that a power-law spectrum is preserved by the deceleration, and that the deceleration contributes a decrease at high energies of about one third of the total modulation. Where the spectrum flattens out at lower energies, the deceleration produces an increase which partially cancels the reduction by convection.

An extensive study of the solar magnetic field is being conducted by Wilcox and co-workers at the University of California, Berkeley, relating the data on the interplanetary field obtained from satellites and space probes to the magnetic field on the surface of the Sun obtained by means of solar magnetograph. One of the recent analyses, carried out in collaboration with Ness of GSFC and completed in 1966, elucidates the solar source of the sectoral structure of the interplanetary field. The sectoral structure was found in the surface field most prominently in heliographic latitudes between 10°N and 20°N . A superposed-epoch analysis of the calcium-plate structure obtained from the Fraunhofer Institute daily maps of the Sun has shown a relation between the structure of the plages and the interplanetary structure.

In another study by Wilcox, the observations made by IMP-1 of the interplanetary magnetic field and plasma have been compared with the 3-hr geomagnetic-activity index K_p . The average K_p is approximately a linear function of the interplanetary field magnitude B in gammas ($\bar{K}_p = (0.33 \pm 0.02) B \pm 0.2$). It appears significant that this relation between $\bar{K}_p$ and field magnitude passes through the origin, whereas the linear relation between $\bar{K}_p$ and solar wind velocity does not. The average K_p is approximately a linear function of solar-wind velocity, but with perhaps different slope and zero-intercept from the similar relation observed by Snyder, Neugebauer, and Rao with Mariner 2. Little correlation is observed between K_p and solar-wind density, but this result is consistent with the interplanetary-sector pattern discussed by Wilcox and Ness. Cross-correlation as a function of time-lag of K_p and interplanetary field (or solar-wind velocity) yields a positive peak correlation at zero lag, suggesting that a large part of the response of the magnetosphere to solar-wind excitation occurs within the 3-hr K_p period.

2. MAGNETOSPHERE: STRUCTURE AND BEHAVIOR

Boundary Effects. At the NASA Ames Research Center, research is being conducted to understand better the interactions of the interplanetary plasma and the geomagnetic field. In a recent study, relations from kinetic theory are combined with results from fluid calculations to attempt a microscopic interpretation of the properties of the solar wind as it flows around the magnetosphere. Proton-velocity distributions are presented as a function of the particle speed and direction for several points in space for representative values of the solar-wind parameters. The results illustrate how the velocity distribution is highly collimated in the incident stream, is completely isotropic at the nose of the magnetosphere, and changes back to that of a highly collimated stream along the flanks of the magnetosphere. Except for a very small region in the vicinity of the magnetosphere nose, the number of particles that move in the upstream direction is insignificantly small compared with the number that move in the direction of the bulk velocity. The most probable speed of the protons, as viewed in a frame fixed in the Earth, is always in the direction of the local bulk velocity, and tends to be relatively constant throughout the flow in spite of substantial changes in temperature and bulk velocity. The results are significant in that a microscopic picture

based on kinetic theory has been established that will provide a more realistic basis for reduction, analysis, and interpretation of the measurements that would be made by various types of instruments commonly used to observe plasma flows in space.

A simplified magnetohydrodynamic (MHD) model of the interface between the solar wind and the geomagnetic field on the tail-side of the Earth has been constructed by Lerche at Chicago. Using linearized MHD theory it is shown that unstable waves can exist that grow exponentially with time. It is also shown that the dominant waves are those having the shortest wavelengths, and consequently a fluid analysis is inadequate since it does not describe the main physical process. Thus, the calculation should be repeated taking into account the finite thickness of the boundary layer and also the finite radii of gyration of the particles involved. The acceleration of particles trapped on the magnetic-field lines by unstable waves is considered qualitatively.

General Models and Theoretical Studies. The basic theoretical properties of nonsymmetric inflation of a dipole magnetic field by ionized gas have been pointed out by Parker at Chicago. It is shown that the distortion ΔB of the field in the neighborhood of the dipole depends very much upon whether there is a nonconducting layer present and upon the configuration of the inflating gas, in contrast to symmetric inflation where ΔB depends only upon the total energy of the inflating gas. Dissipation of the nonsymmetric portion of the inflating gas is rapid because nonsymmetric inflation drives a current down along the magnetic lines of force and across the ionosphere. Dissipation is also rapid because of the nonsymmetric distortion of the field, whose pattern rotates with the azimuthal drift of the inflating gas. The high rate of dissipation implies that nonsymmetric inflation can probably be important only during the active phase of a magnetic storm.

At AFCRL, theoretical studies are being conducted on the effects of the solar wind on the geomagnetic field; relationships between geomagnetic-field variations and resonant properties of the magnetosphere; models wherein geomagnetic variations are treated as hydromagnetic waves propagating in a plasmasphere permeated by a dipole field; and the examination of the solar wind for intrinsic stabilities. A fundamental theorem for shielded magnetic disturbances has been derived and applications to the geophysical environment are being developed.

In the last few years an intensive theoretical study has been made at AFCRL of axisymmetric hydromagnetic resonances. The toroidal mode is most unusual in that its eigenvalues are functions of spatial coordinates. It has been shown that this degeneracy is removed when the parallel current density term is retained in the generalized Ohm's Law and the resulting eigenvalues are discrete and constant. As a consequence, earlier results based on vibrating field lines must be rejected.

An analytical statistical study of possible geomagnetic disturbances that might be caused by the Moon was carried out during 1966 by Dessler at Rice University. It was concluded that the available data do not indicate any statistically significant lunar influence on geomagnetic activity. Previously reported effects with a periodicity of 29.53 days, attributed to the Moon, are actually due to the Sun. The lunar orbital period falls within a broad peak of magnetic activity induced by the Sun with almost the same periodicity—the well known M-region effect.

A theoretical study, also made at Rice University, of the maximum plasma density in the geomagnetic tail showed a significant disagreement with the interpretation of recent ground-based radar data. From these measurements, it was concluded that the electron number density in the geomagnetic tail was approximately $2 \times 10^2 \text{ cm}^{-3}$. The theoretical analysis indicated that either the tail should be filled principally with solar plasma having a number

density no greater than about $10/\text{cm}^3$ or that some important physical process had been overlooked that is capable of condensing plasma in the tail to a high concentration.

The Space Sciences Department of the Douglas Aircraft Company is studying the morphology of geomagnetically trapped particles and solar cosmic rays. A previously developed computer program that calculates the total trapped-particle intensity to which a satellite would be exposed has been updated and refined. Particular attention was paid to synchronous orbits and the time behavior of the particles. In the last few years, several satellite investigators have published improved analyses of their earlier data. The Douglas group is using this more detailed information to re-analyse the major solar cosmic-ray events of the last solar cycle, and is also continuing to analyse new events as they occur.

Using spherical harmonic analysis, AFCRL has started work on a new model of the Earth's magnetic field for epoch 1965.0, based upon a sample of all available data, including the OGO-2 total-intensity data and World Magnetic Survey data. Coefficients for the main field and for the secular variation will be determined using both a spherical and a spheroidal reference Earth. Models of the main field using space results have been computed at GSFC by Jensen and Cain.

Plasmasphere Structure and Behavior. The position of the plasmapause as a function of various indices of magnetic activity is being investigated at the Radioscience Laboratory of Stanford University. A study was made of the relation between the equatorial radius of the plasmapause near local dawn and the magnetic indices D_{st} , K_p , and local K at Byrd Station (near the meridian of the plasmapause measurement). The plasmapause radius was found to be highly correlated with each of the indices, shorter equatorial radii being observed during periods of greater disturbance. It was found that the correlation is significantly higher for magnetic indices which reflect the behavior of the polar substorm; that is, there was a higher correlation between the plasmapause position at local dawn and the planetary K_p index and local K at Byrd Station than for the plasmapause radius and D_{st} , a measure of ring current activity. This result supports the finding that the plasmapause is driven rapidly inward on the nightside of the Earth during polar substorms.

Direct detection of the magnetospheric electric field associated with a polar substorm is also being made at Stanford using the whistler method which provides a unique way of studying the bulk motion of magnetospheric ionization. Tubes of ionization are identified by means of the whistlers that propagate along them, and movements of the tubes are tracked by detection of gradual changes in the parameters of the observed whistlers. The method may at a given time be applied to a relatively large region in space, and thus affords a unique opportunity to study large-scale bulk motions and their associated $\mathbf{v} \times \mathbf{B}$ electric fields. A close connection has now been found between polar substorms and plasma motions in the vicinity of the plasmapause. Several cases were identified in which a large, transient, inward motion of magnetospheric plasma occurred during a polar substorm. The temporally isolated substorm of July 15, 1965, about 0600 UT, was studied at two high-latitude conjugate stations. The electric field was measured at a lower latitude some 20 to 30 min prior to the magnetic bay indicating the substorm proper. The electric field set in abruptly within a period of less than 5 min, and lasted 1 to 2 hr. During the substorm the plasma at $4 R_E$ was driven inward at velocities approaching one half the velocity the plasma would have if it were simply co-rotating with the Earth. The associated component of electric field was westward in direction, having a magnitude in the equatorial plane of approximately 0.3 mV/m, which corresponds to a potential difference of about 2 kV/ R_E .

3. HYDROMAGNETIC FLUCTUATIONS, WAVES, AND PROPAGATION

The study of the nature and origins of rapid geomagnetic fluctuations covers the frequency-range 0.001 to 50 Hz and is primarily concerned with the quasi-sinusoidal oscillations of the field that originate in hydromagnetic phenomena in the magnetosphere or ionosphere. Three-component tape recordings of the fluctuations are made in the field by AFCRL. Analog and digital analyses are then combined to determine the polarization characteristics of the recorded signals. A continuous rotation of the horizontal component of the disturbance vector in a selected, octave-bandwidth frequency range is taken as a sufficient, though not a necessary, indication of a propagating wave. The simultaneous occurrence of hydromagnetic waves of different frequencies, not previously observed, has been demonstrated and periods ranging from 30 sec to 15 min have been found. The limited data so far processed suggest a characteristic frequency pattern. Similar, but more direct, data from probes or satellites would greatly enhance this approach to the study of magnetospheric phenomena.

For making detailed studies of the longer-period magnetic variations, variable-area magnetographs (horizontal component only) are operated by AFCRL at six stations distributed from polar to equatorial latitudes principally near the 75° W meridian. An electromechanical scanner-analyser is used to convert the analog-type variable-area magnetograms to digital (punched-card) information on the variation of the horizontal component of the Earth's field.

Pg-type micropulsations of about 100-sec period have been studied by Wilson of the Geophysical Institute, University of Alaska, at conjugate point stations. All the characteristics of these long-period oscillations were found to be identical at different ends of the same field line, indicating that they are due to transverse hydromagnetic waves propagating along the field lines from an excitation source deep in the magnetosphere. The three-dimensional polarization of the Pg at conjugate points can be explained in terms of resonant field-line oscillations of symmetric and antisymmetric modes. The magnetic perturbation of the Pg's as measured at the Earth's surface is explained in terms of a rotating current system induced in the ionosphere by the transverse hydromagnetic waves.

For several years, the U.S. Army Electronics Command (USAECOM) at Ft. Monmouth, N.J. has been conducting theoretical and experimental studies relative to the structure of the magnetosphere and to the propagation of hydromagnetic disturbances through the ionosphere and exosphere. For this purpose, both natural ELF disturbances (generated by solar wind) and manmade signals (generated by high-altitude nuclear devices) have been recorded at a number of field stations and analysed from the standpoint of various theoretical concepts. Interesting results have been obtained concerning the excitation of ELF resonances in the exosphere and concerning the role of mode-coupling in these effects.

During the total solar eclipse of November 12, 1966, USAECOM also operated a magnetic and telluric field station at Nana, Peru, in the path of totality of the eclipse and obtained very interesting data that prove the existence of solar-eclipse-induced magnetic effects. Some indication of these effects had already been observed during the July 20, 1963 eclipse at a network of magnetic stations along the eastern seaboard of North America; at that time, however, both instrumentation limitations and the presence of strong natural disturbances of other origin had precluded an exhaustive analysis of the data. The new data from Peru are of excellent quality, and a detailed theoretical analysis is under way, which will enable a determination of the height of the solar-eclipse-induced ionospheric current systems as well as of the ionospheric-recombination time at that height.

Studies of the phenomena associated with the upper cutoff of ducted whistler waves in the magnetosphere were made at Stanford's Radioscience Laboratory during 1966. The whistler cutoff is an abrupt effect taking place above the nose frequency and frequently involving a decrease in intensity by 10 dB or more within a fraction of a kHz. Recent measurements showed that well-defined whistlers tend to cut off within about 5% of $f_{H_0}/2$, where f_{H_0} is the minimum gyrofrequency along the field line. Since a cutoff at about $f_{H_0}/2$ is predicted theoretically for propagation in ducts of enhanced ionization, the results strongly suggest that the cutoff is a propagation phenomenon and is not predominantly a Landau-damping effect. A number of related observations suggest, however, that there is some kind of instability associated with the cutoff. It was found that the most common type of triggered noise observed inside the plasmasphere begins at the upper cutoff and involves quasiconstant tones lasting from about 0.01 to 2 sec. Furthermore, it was found that the upper cutoff frequency is the most favorable frequency for triggering of noise by low-power fixed-frequency transmitters. On the few occasions when noise was observed to be triggered by whistler-mode signals from the 100-watt 10.2-kHz Omega transmitter at Forest Port, New York, the propagation occurred along the path on which the minimum gyrofrequency was within a few percent of twice that of the transmitted frequency.

4. AURORAL STUDIES

Micropulsations and Correlations with Precipitation. A program of study of micropulsations of the geomagnetic field, in conjunction with three balloon experiments conducted by Anderson and his group, was initiated some three years ago by Ward and co-workers at Berkeley (see Chapter 5, Section 6). The objective has been to make simultaneous observations of precipitation events in the auroral zone and concurrent electromagnetic variations to clarify the nature of both classes of phenomena and their interdependence. During the last three years, simultaneous observations of particle precipitation and magnetic variations in the auroral zone have been made at Flin Flon, Manitoba, Canada. These experiments were directed first toward establishing correlations between the two phenomena, and more recently, toward studying the details of these correlations. The work during the past year is summarized below.

(1) Using digital filters, a computer program was written to be used in obtaining digital dynamic spectra. A small amount of pearl-pulsation data, recorded on chart paper, was digitized and subjected to analysis. In comparing the results with analog sonagrams, the digital technique proved to be superior, although more expensive. Further computer programs were written that were based on the present theoretical understanding of the generation of pearl pulsations. Using the results of the digital sonagram, the magnetospheric plasma density as a function of radial distance was derived. Further digitization of pearl data, which will be subjected to a similar analysis, is in progress.

(2) Data published by the Geophysical Institute, University of Alaska, were used to obtain more information on the conditions necessary for the generation of pearl pulsations. It was shown that the probability of occurrence of pearl pulsations on the day that an interplanetary-magnetic-field sector boundary passed the Earth was three times as great as in the middle of a sector. Furthermore, pearl occurrence is dependent on magnetic activity, provided that the local time-dependence is also taken into account.

(3) During the summer of 1965, an interesting correlation was observed between magnetic impulses and x-ray microbursts caused by precipitating electrons. The correlation was observed during one of five microburst episodes for which simultaneous magnetic data were available. During a 20-min period at the end of this episode, magnetic impulses were correlated with x-ray microbursts; this relationship evolved from almost no correlation to a one-to-one correlation.

(4) Another, less direct, correlation between micropulsations and electron precipitation has been established. Microbursts recorded at Flin Flon always occur simultaneously with short-period (5-to-40 sec) micropulsations recorded at College, Alaska (60°W). The riometer at College indicates that electron precipitation is occurring there at the same time as the micropulsations. Furthermore, the magnetometer indicates that a magnetic bay is in progress. These observations indicated that certain electron-precipitation and micropulsation phenomena are intimately related to auroral substorms.

(5) On a basis of the results summarized above, numerous changes were made in the 1966 instrumentation. Particular attention was given to both FM-tape and digital-tape recording of the micropulsation data. Altitude and position data were acquired for the balloon payloads. Suitable arrangements of the detectors allowed determination of x-ray source sizes and source velocities. Decisions were made to fly payloads in such a way as to maximize collection of auroral substorm data.

(6) Detailed analysis of the most recent data has shown that many of the auroral-zone micropulsations as well as electron precipitation are manifestations at certain local times of various phases of the auroral substorm. Furthermore, it is found that certain types of micropulsations and electron precipitation always occur together, suggesting causal relations between them. The details of the relations of these phenomena to the auroral substorm and to each other are being studied.

A study of interplanetary-magnetic-field values obtained by Mariner 2 corresponding to the geomagnetic storm of October 7, 1962, was also undertaken in order to determine the influence of the interplanetary magnetic field on the level of geomagnetic-micropulsation activity. It was found that, especially at high latitudes, the presence of an exterior field with a southward component (toward the south ecliptic pole) is associated with higher levels of micropulsation activity. This may be interpreted as evidence for the transport of energy into the magnetosphere by means of reconnection of the interplanetary and geomagnetic lines of force as suggested by Dungey. The stations used in the analysis were located at Byrd Station, Antarctica, and Puerto Rico.

Auroral Morphology and Luminosity. The meridian chain of three scanning-photometer stations and nine all-sky camera stations was maintained in operation by the Geophysical Institute as part of the IQSY program until April 1966. Emphasis during 1966 was placed on selection and analysis of the data with the following results, some of which are preliminary: (1) Auroral morphology: The latitude of maximum incidence of auroral forms (dip latitude 66.5°N) has not changed between the IGY and the IQSY, but the relative incidence has decreased at latitudes below the peak and increased above. Isoauroral diagrams derived from IQSY all-sky camera data show that the auroral-oval concept represents quite well the gross behavior of the aurora inside the auroral cap and negates the concept of a separate inner auroral zone. Dip latitude 78°N is a transition region between generally east-west-aligned features of the statistical auroral zone and Earth-Sun-oriented auroral arcs inside the polar cap. (2) Auroral photometry: the photometric data are being analysed from two points of view: the characteristics of the primary auroral particles and the atmospheric processes responsible for the auroral optical

emissions. In the stable auroral arcs observed prior to breakup, electrons have characteristic energies of 1 to 6 keV with fluxes of 10^7 to 10^{11} electrons/cm²sec. Protons are precipitated southward of the electrons with characteristic energies of 10 to 30 keV and fluxes of 10^4 to 10^6 protons/cm²sec. During the auroral breakup, electrons and protons are both precipitated into the breakup arc with increased energies and fluxes. In particular the proton energy probably increases by a factor of 10. Analysis of the photometric data in terms of volume emission rate profiles shows that the horizontal profiles of λ 5577 [OI], λ 3914 (N_2^+), and λ 6300 [OI] are different and increasingly wider. For the latter this is interpreted as diffusion of the long-lived O(¹D) atoms at high altitudes. Collisional deactivation of O(¹D) is important below 250 km. For the former the data are interpreted to rule out secondary electron excitation as a dominant process for the production of λ 5577 in aurora.

Four image-orthicon television systems have been placed in operation at College for the study of auroras. During 1966 the program, under the direction of Davis, consisted primarily of data collection. Analysis has concentrated on the determination of auroral widths: it is found that most auroras consist of single or multiple elongated structures having widths in the range of 100 to 300 m.

Theoretical Study of Ring Current and Aurora. During the past year, Swift at the Geophysical Institute has carried out theoretical studies of the formation and possible instabilities of the ring-current belt. It has been shown quantitatively that if energetic protons are injected primarily on the day-side of the magnetosphere, patterns of charge transfer between the magnetosphere and ionosphere develop that are consistent with observed positions of electron and proton auroras. If the region of the ionosphere where the auroras occur is assumed to have enhanced conductivity, ionospheric electrojets develop that are consistent with observed electrojet patterns. Studies of the ring-current flute instability indicate growth times and wavelengths consistent with the time and distance scales of the auroral breakup. Studies of the universal-type instability associated with a field-aligned column of enhanced plasma density show frequencies and growth rates that are consistent with observed frequencies of Pg-type micropulsations.

5. OTHER HIGH-LATITUDE STUDIES

Neutron Events. Analysis of data obtained by the Bartol Research Foundation neutron-monitor stations and others in the world-wide network revealed that the amplitude of the solar diurnal variation was significantly reduced during the year of the most recent cosmic-ray intensity maximum as compared with the epoch of minimum intensity. The conclusion that the "steady-state" anisotropy is not invariant is confirmed by the Carnegie Institution ionization-chamber measurements, which further indicate that the two previous solar cycles were similarly characterized by amplitude reductions. This result implies changes in scale size and/or distribution of magnetic-field irregularities superimposed on the Archimedean spiral structure.

After a lapse of five years, the first solar-particle emission that produced detectable effects in ground-based detectors occurred on July 6, 1966, and was the first such event observed by the Bartol network of high-counting-rate neutron monitors now operating in both polar regions. A second, and larger, ground-level event occurred on January 28, 1967.

A systematic cosmic-ray intensity gradient along the Earth's rotational axis, arising from a spatial anisotropy almost perpendicular to the plane of the ecliptic, has also been observed for the first time. Analysis of data recorded by the network of high-counting-rate neutron monitors during the recovery phase of a Forbush decrease in March 1966 revealed the occurrence of a significant north-south asymmetry. A theoretical model that accounts for all the observed effects, including the latitude dependence, envisages the anisotropy as arising from the diffusion of cosmic rays through disordered magnetic fields in the vicinity of the Earth, associated with a profusion of solar disturbances that were conspicuous during this period of resurgent solar activity.

Ionospheric Forward Scatter. An analysis of data obtained with the ionospheric forward-scatter network operated in the Northern and Southern Hemispheres in a collaboration between Bartol and ITSA has led to conclusions concerning the spectra of electrons that are precipitated in and near the auroral zone. Several PCA events were observed, with the rate increasing with the level of solar activity.

A study of the sporadic-E mode of signal propagation revealed that the diurnal variations at magnetically-conjugate midpoints, Byrd - South Pole in Antarctica and Frobisher Bay - Great Whale River in Canada, are identical in geomagnetic time. The relationship of the occurrence of E_g and geomagnetic activity was also established.

Radio Absorption. The Douglas Aircraft Company's geophysical observatory program includes stations at McMurdo Sound, Antarctica ($77^{\circ}51'S$, $166^{\circ}43'E$, geographic coordinates), and at the magnetically-conjugate location, Shepherd Bay, N.W.T., Canada ($68^{\circ}49'N$, $93^{\circ}26'W$, geographic). These stations, at a magnetic latitude of 80° , poleward from the auroral zone, were established to study solar-cosmic-ray events. Riometers at 30 and 50 MHz and magnetometers are being operated. The absorption of cosmic radio noise measured by the riometer is proportional to the square root of the intensity of charged particles for a fixed energy spectrum. The five events observed in 1966 and the one in 1967 indicate a significant increase in solar-cosmic-ray activity. (For comparison, only one event in 1965 and one in 1964 were observed.) From July through September 1966, four events occurred. The September 2, 1966 event had a maximum of 13 dB and was the largest since the July 18, 1961 event. The next largest event observed occurred on January 28, 1967, and reached a maximum of 7 dB.

Studies by ITSA of high-latitude radio absorption using spaced riometers are providing information about the apparent movement of auroral ionization in the ionospheric D region. Stations separated by up to 176° of magnetic longitude around the auroral zone show that the absorption-producing disturbances tend to begin near magnetic midnight and to propagate both eastward and westward to the day-side of the Earth, the whole sequence taking on the average about 45 min. This suggests that the sources of the night and day regions of auroral absorption are in some way associated, rather than, as is sometimes thought, independent. At some stations, multiple riometer systems using several antennas pointed away from the zenith have been used and these are showing apparent movements over distances of about 300 km. At geomagnetic latitude 60° , eastward and westward movements are less pronounced than a general movement towards the equator with average velocity 70 km/min. With these and other studies it is hoped to construct a reasonably complete global picture of the movement of absorption-producing auroral precipitation.

High-Latitude Magnetic Activity. The auroral electrojet activity index AE has been derived for the year of 1958 and a portion of 1961 by Davis at the Geophysical Institute, and similar indices have been generated for the purpose of studying magnetic variations in the two polar-cap regions. These studies show a large seasonal variation in the polar-cap activity and indicate at least two sources of this activity. The AE index is being compiled for all periods between 1957 and 1965.

Upper-Atmospheric Physics

1. RADAR BACKSCATTER OBSERVATIONS

Regular observations of the ionosphere have been carried out in Puerto Rico at the Arecibo Ionospheric Observatory of the Cornell Center for Radiophysics and Space Research. Electron-density, electron-temperature, and ion-temperature profiles in the altitude range 130 to 1400 km have been measured. Time resolution for these measurements in the E and F regions is about 10 min, with a height resolution of 6 km using the double-pulse autocorrelation technique. A detailed study of the ionospheric heat balance is being made using these data in the E and F regions. Autocorrelation functions measured below 130 km indicate that ion-neutral collisions may be important in this range, and an experiment is being set up with 3-km height resolution to determine these effects.

Measurements of traveling disturbances (waves) in the F region have been made by beam-swinging and are being continued. Fine structure in electron-density profiles has been measured in the E region and some characteristics of the structure, formation, and vertical motions of sporadic-E layers have been deduced from these measurements. Beam-swinging techniques applied to the E region have shown the existence of irregularities (E_g) with horizontal scales of 1 to 10 km; the large uncertainty is due to unknown horizontal velocities of the irregularities. A two-beam experiment will be attempted with improved height and time resolution, achieved by frequency coded pulsing, which should greatly improve the capability of measuring gradients and motions in both the E and F regions.

Plasma-line observations have produced precise electron-density profiles that have been compared to backscatter power profiles to deduce electron-to-ion temperature ratio. These results show that in summer, a maximum temperature ratio of 2.0 occurs at an altitude of 200 km, while at 350 km and 120 km the ratio becomes 1. Efforts to measure the absolute intensity of the plasma lines have been made in order to obtain the energy spectrum and number density of photoelectrons in the ionosphere.

Photometric studies of 6300 Å airglow are being made in conjunction with the predawn enhancement of electron temperatures that has been interpreted as a streaming of photoelectrons from the magnetic conjugate-point ionosphere. Preliminary measurements have confirmed the

coincidence of 6300-Å airglow enhancement and electron-temperature predawn heating within the 10-min time resolution of the experiment.

During the November 12 solar eclipse, observations were made at Arecibo to examine the ionospheric changes during a partial eclipse at Arecibo followed several hours later by a partial eclipse at Arecibo's magnetic conjugate. The results, relating to temperatures and ionic composition in the lower magnetosphere that are essential to understanding the physical and chemical processes in the medium, are being analysed by Gordon of Rice University. It is hoped that this new information will assist in explaining the movement of ions along magnetic lines of force in the Earth's magnetic field.

There have been two major experimental developments at Jicamarca Radar Observatory during 1966. (Jicamarca is a cooperative activity of the Institute for Telecommunication Sciences and Aeronomy of ESSA and the Instituto Geofísico del Perú.) The first was the observation in the spectrum of incoherent backscatter of proton gyroresonances as predicted by plasma physics theory but hitherto unobserved. Although it was originally expected that gyrations of heavier ions could also be detected, present theory would suggest that this is only promising for helium ions, which are rare. A second significant observation is the time variation of the neutral gas temperature in the 300-to-400 km height region. It has been demonstrated theoretically that in this height region, except for the sunrise period, the neutral gas is essentially at the same temperature as the electron gas, hence, monitoring electron temperature is tantamount to observing the neutral temperature. The time resolution of this measurement is excellent, and an appreciable quantity of data has already been obtained, commencing late in 1966. These observations should contribute significantly to the body of knowledge on neutral temperature, heretofore derived mainly from satellite-drag measurements.

Because of its fortunate location in the center of the zone of totality of the November 12, 1966 eclipse, Jicamarca was able to obtain some excellent data regarding the height and time variation of electron concentration, electron temperature, and ion temperature during the eclipse. Pronounced eclipse effects were observed, and interpretation of the data is presently under way. It appears that vertical ionospheric drifts were occurring and must be taken into account.

Electron and ion temperatures and ion composition to 100 km and above are being observed systematically and the Jicamarca results are being compared with those obtained from satellites. More frequent measurements of electron concentration to exospheric heights (up to 10,000 km) are now being made. Increased automation and technological improvements have resulted in an appreciable increment in the percentage of observing time.

The theory of incoherent scattering has been advanced by further treatment of the non-equilibrium case (unequal electron and ion temperatures) and considering the effect of a magnetic field. The magnetic-field effect is appreciable at Jicamarca, in view of the nearly perpendicular incidence of the radar beam with the almost horizontal field lines.

In addition to observations of proton gyroresonances noted above, further studies of the ionospheric plasma above Jicamarca have been made. These include an analysis of experimental observations of secondary irregularities in the equatorial electrojet and a theoretical explanation of the origin of many of these secondary irregularities, based upon the non-linear coupling of unstable plasma waves. Additional experimental studies of electrojet irregularities have been undertaken around the clock, providing further information regarding a current-reversal that is observed both at sunrise and at sunset. It has also been noted that

the velocity of the electrojet irregularities varies somewhat with time, and this change is being attributed to the modulation of the ion-acoustic velocity by horizontal neutral winds. If this interpretation is correct, observation of the electrojet irregularities can provide a new method for the monitoring of neutral winds. Coherent scatter from 3-m irregularities at 6000 km above Jicamarca has been reported. These echoes which faded at about 1 Hz, were obtained during some nights in April and May of 1964. Echoes of this type have not been observed since. Studies of the spectrum of F-region irregularities ("spread-F irregularities") observed at various angles in the equatorial plane have also been reported.

A theory reported by Weinstock has been developed at ITSA that allows the magnitudes (amplitudes) of ionospheric irregularities to be deduced from measured intensities of radar backscatter (echoes). This theory is based on the interpretation of ionospheric irregularities as macroscopic plasma inhomogeneities. The usual theory of scattering is then extended to include the occurrence of such macroscopic inhomogeneities. The theory has been applied to the E-region irregularities probed by the Jicamarca Radar Observatory; the backscatter from 6-m wavelength irregularities can be explained by irregularity amplitudes as small as a few electrons/cm³.

The incoherent backscatter measurement program carried on at the Millstone Hill site of MIT's Lincoln Laboratory during 1966 consisted principally of a continuation of the types of measurements reported for 1965. In particular, the use of the steerable L-band system (1295 MHz) has provided reliable measurements of electron density in the region between 100 and 200 km.

2. OTHER RADIO AND RADAR OBSERVATIONS

The Institute for Exploratory Research of the U.S. Army Electronics Command (Ft. Monmouth) and the University of Illinois have continued their joint study of the Faraday rotation of lunar radar echoes to derive diurnal, seasonal, and secular variations in the ionospheric electron content. Two frequencies are now used, 150.6 MHz and 413.25 MHz, which permit resolution of the angular ambiguity that exists with the lower frequency alone. Signals are transmitted by USAECOM and are received and analysed by the University of Illinois. Observations have been made for a period of about 2 weeks each month since the summer of 1961 and will be continued to the peak of the present solar cycle. A four-volume atlas has been prepared that contains the individual daily records for the calendar years 1961 through 1965. Additional volumes are planned for future years. It is hoped that such an atlas will be useful to theoretical workers and to those measuring the ionospheric electron content by other methods.

A radio technique is used by ITSA to study enhanced electron production in the E and F layers of the ionosphere at the time of visible solar flares. The technique involves the frequency analysis of HF signals, and essentially measures the time rate of change of the enhanced electron content below the reflection level. The x-ray bursts detected are of the impulsive type only and occur near the times of the explosive phases of the H α flare. They appear to be closely associated in time with impulsive bursts of cm radio noise. With this technique the ionosphere is used as a gigantic ion-chamber to study the spectrum of solar radiations in the range from about 5 Å to about 500 Å. It has been found that flares that produce ionospheric effects contain a considerable flux (up to 50%) at wavelengths greater than about 100 Å. These studies also give information

about the ionosphere. For example, most of the ionization produced by a flare is in the E and F regions rather than in the D region. Furthermore, the relaxation time of this part of the ionosphere appears to be of the order of 0.5 to 1 min.

A meteor trail system for determining winds in the 80-to-96 km region was completed at the Smithsonian Astrophysical Observatory's Illinois site. Unexpected delays have been encountered in the completion of the computer program. Previous hopes that density could also be obtained appear unrealizable.

Three lines of telluric ozone, at 30.056, 36.025, and 37.836 GHz were studied both in emission and in absorption against the Sun by Caton, Welch, and Silver at Berkeley. Both emission and absorption were detected in amounts that agreed reasonably with theoretical predictions based on the ARDC standard atmosphere. The absorption of the 37.836-GHz line referred to the zenith was about 0.05%.

3. AIRGLOW AND OTHER OPTICAL OBSERVATIONS

AFCRL measurements of the 5577 Å (OI) and 6300 Å (OI) airglow-emission intensities made from a jet aircraft in the region of the South Atlantic magnetic anomaly showed an absence of the increased intensity that might have been anticipated due to particle precipitation in this region. This unexpected result raises questions regarding the mechanism of energy degradation of the precipitating particles.

The phenomenological behavior of the 6300 Å (OI) airglow emission as observed at Sacramento Peak, New Mexico has also been studied by AFCRL. It was found that the general behavior could be classified in three groups: (1) a monotonic decrease during the night, typical of temperate-latitude stations, on days with little or no magnetic disturbance; (2) a variable emission occurring on magnetically disturbed nights; and (3) a variation with a maximum during the night, usually to the south, that appears to be a northern extension of the equatorial behavior. The increase of intensity of the 5577 Å (OI) airglow emission associated with a magnetic storm commencement, previously noted by Glaume, was confirmed using data from Sacramento Peak, Tonantzintla (Mexico), and Huancayo (Peru). The time of the maximum intensity following the SSC of the order of 1 hr and the amount of the increase of the order of 5% are comparable to those previously noted at Haute-Provence and Taman-rasset. AFCRL data, however, indicated that the effect began prior to the SSC.

An AFCRL airborne measurement of a CaII cloud with a spatial extent of about 75 km was made during twilight. A minimum height of 120 km was estimated from the solar depression angle. This is believed to be the first time a Ca cloud has been detected.

A technique for measuring the airglow continuum in the immediate vicinity of the strong line-emissions of the airglow was developed and tested by AFCRL by introducing a second rotating polarizer in a birefringent filter photometer. The results were compared with those obtained by other workers using different techniques.

The feasibility of measuring atmospheric density at 60 km with a laser searchlight was demonstrated at the University of the West Indies. Tests are under way to extend this capability to 100 km.

4. THEORETICAL AND ANALYTICAL STUDIES

A simple model was developed at AFCRL for the decay of the lower F region during the night. The study demonstrated that good correlation exists between the decay of NO^+ and O_2^+ ions during the night and the intensity of the oxygen red line. In the last third of the night, poor correlation was taken to indicate the effects of nondiffusive transport. Studies of the daytime D region suggest a minimum production rate of $0.1 \text{ ion pairs/cm}^3\text{sec}^{-1}$ near 80 km. A suggestion was put forward that methane derivatives, particularly CH_3 , may be important in the D region.

The Space Sciences Department of the Douglas Aircraft Company is continuing its studies of the lower ionosphere and airglow in order to interpret satellite, rocket, and ground-based observations, and the effect of solar cosmic rays. A model of the ionospheric D region, involving positive ions, negative ions, and electrons, has been proposed. All negative ions have been taken into consideration in the model, although the predominant one was found to be NO_2^- . Besides this ionospheric model, the seasonal and diurnal variations of day, twilight, and night sodium airglow have been effectively explained on the basis of the seasonal and diurnal variations of H and OH number densities, in addition to the variations of O and O_3 number densities. Attempts are being made to calculate quantitative number densities of Na and Na^+ but the accuracies of the calculated values suffer from a lack of measured data for specific reaction rates.

Mean wind analyses by AFCRL above 120 km indicate tidal dominance of winds in the altitude region 120 to 180 km. The linearized tidal theory does allow a tentative identification of the dominant tidal modes in this range, and indicates that the diurnal mode changes at some altitude between 125 and 135 km. The modes identified by this process are the 2,4 component of the semidiurnal tide in the summer and the 2,6 component in the winter. Also, the empirically determined relation between scale height and observed wavelengths is explained. Other AFCRL studies in this field included a statistical analysis of winds between 80 and 180 km altitude using 75 wind profiles previously reported by various participants in the COSPAR ionospheric wind program. Strong dependence of midlatitude zonal flow on altitude and of total velocity on altitude were found in the summer but not in the winter. The frequency spectrum of the vertical profile of horizontal winds showed a consistent pattern with the r.m.s. residual fluctuations of these profiles inversely proportional to the spatial frequency (expressed in reciprocal scale-height, RSH). Specifically, a 40 m/s residual fluctuation existed for frequencies of 0.2 RSH, and a 4 m/s residual existed at 2 RSH.

The AFCRL rocket-borne chemical release measurements were supplemented by theoretical and laboratory studies of: (1) Wind-shear effects on ion layering (sporadic E); (2) Problems of temperature equilibration of radiating species at low pressure (AIO radiation); (3) Problems of expansion and shock formation in photochemistry (NO release); (4) The relation of wind shear and turbulence in the 30-to-80 km region (Al_2O_3 smoke release); and (5) The relation of radio-reflection characteristics to the size, shape, density distribution, and orientation of ionospheric irregularities (barium-ion release). These studies can be further described as follows:

(1) A method has been developed at AFCRL for experimentally determining the effective production and loss parameters that are important in producing sporadic-E layers. An improved method has been developed for estimating ionospheric wind altitude profiles as determined by ground-based photography of rocket-deposited chemiluminous trails.

(2) The validity of the aluminum oxide (AlO) fluorescent spectrum method for determining upper atmospheric temperatures has been examined. Up to 170 to 180 km, there are sufficient thermalizing collisions between solar excitations so that the lower vibrational levels are populated according to the Boltzmann distribution.

(3) The upper atmospheric nitric-oxide releases have been simulated in a low density wind tunnel. Empirical light-emission rate constants have been obtained, and the gas-dynamic model for the nitric oxide release has been substantiated.

(4) The theoretical radial growth rate in the 30-to-80 km region as proposed by Tchen for shear-induced turbulence was found to exist, through measurements of the smoke releases, thus establishing a relationship between wind shear and turbulence in this region.

(5) The expected radio-frequency cross section of the field-aligned barium-ion cloud was computed. Account was taken of released quantity and altitude, probing radio frequency, aspect of the radio-frequency beam with respect to ion-cloud and field lines, and time after release. The rear-aspect target was found to be markedly smaller because of its asymmetry, and to be smaller in the interval from 100 to 1000 sec than in the intervals from 10 to 100 sec and from 1000 to 10,000 sec. This was confirmed by the observations.

Work continued during 1966 on refinements of tables describing the thermodynamic properties of the atmosphere. The Interim Air Force Supplemental Atmospheres, tables of surface-to-90 km atmospheric properties by season and latitude, were modified in the 80-to-90 km altitude region and extended upward to 120 km to join with three families (summer, winter, and spring/fall) of 120-to-1000 km atmospheres. This work was performed by AFCRL in conjunction with the U.S. Committee on Extension to the Standard Atmosphere, COESA, and was published by the Government Printing Office in a companion volume to the U.S. Standard Atmosphere, 1962, as the U.S. Standard Atmosphere Supplements, 1966. As in the past, these refinements have led to still further requirements for detail, and several studies have now been prepared showing the monthly profiles of atmospheric properties through the mesosphere.

Available information on humidity in the stratosphere is being refined by an AFCRL experimental program, near completion. A profile of stratospheric humidity for midlatitudes has been developed which (1) is extremely dry just above the tropopause, in agreement with most theories and experiments, (2) shows a slight increase in moisture content to an altitude of 25 km, in agreement with independent observation of nacreous clouds and maximum altitude of cumulonimbus penetrations, and (3) has an upward decrease in humidity thereafter. When the gradient at the highest levels, about 30 km, is extrapolated to altitudes of noctilucent clouds at 80 km, agreement with water vapor noted in these clouds is obtained.

AFCRL efforts to describe more accurately the atmospheric turbulence at altitudes from 30 to 60 km have been continued. Preliminary smoke-puff and smoke-trail data were analysed for various scales of turbulence taking place at these altitudes. All levels showed varying degrees of small scale motions. An analysis of radio meteor trails has resulted in the determination of certain turbulent parameters, namely the rate of viscous dissipation (ϵ), the turbulent intensity ($\sqrt{k_k^2}$), the length scale of the isotropic part of the turbulent energy spectrum (l_k), and the local Reynolds number (Re_k). These measurements affirm the previous result that although there is an isotropic part to the turbulent spectrum, there does not exist an inertial subrange in the upper atmosphere.

Time-dependent variations of O and O₂ concentrations in regions between 70 and 170 km have been calculated by Shimazaki at ITSA, by taking into account molecular diffusion and mixing effect due to vertical eddy diffusion, as well as photodissociation and recombination processes. Results indicate that atmospheric diffusion and mixing play an important role

in determining the O and O₂ distributions. These distributions finally approach a steady state in which the dissociation term is balanced with the transport term due to molecular diffusion in higher regions, while the recombination term is balanced with the transport term due to eddy mixing in lower regions. Comparison of the calculated height variations in O/O₂ and the mean molecular weight with recent rocket observations indicates that the vertical eddy-diffusion coefficient is about $10^7 \text{cm}^2 \text{sec}^{-1}$ with a tendency to decrease slightly in lower regions. The seasonal and solar-cycle variations in the electron density in the F region may be explained by invoking the variations in the turbopause as well as those in temperature and solar fluxes. It was found that the homopause is generally lower than the turbopause.

A model has been devised at the University of Pittsburgh to explain how charged aerosols can be concentrated by wind-shear Lorentz forces into a thin layer 1-km wide at an altitude near 95 km. Such a layer is required to serve as a source for the neutral sodium layer observed in rocket flights by the University and by Kitt Peak National Observatory. The dust requirements agree with those measured in micrometeorite-collection experiments.

Meier from the University of Pittsburgh is working with Mange in NRL's program to measure the Lyman- α radiation scattered by atomic hydrogen in the Earth's upper atmosphere. Meier plans to apply the methods of radiative transfer theory to the experimentally observed Lyman- α intensities in order to obtain the density distribution of atmospheric hydrogen. NRL's computing facilities will be used to find numerical solutions of the equations of transfer.

Moon, Planets, and Meteorites

1. MOON

Thermal Emissivity. Although ground-based mid-infrared spectral observations of the Moon in support of balloon and rocket experiments were continued during 1966 by AFCRL scientists, the main effort in ground-based telescopic studies was directed to infrared imaging. Lunar infrared (8 to 14 μ) images were constructed having the highest spatial resolution yet obtained, using both the Perkins 183-cm telescope at Lowell Observatory and the AFCRL 60-cm telescope. Of particular interest were infrared images of the thermal anomaly associated with the crater Tycho, which were obtained during the lunar night after Tycho had ceased to be illuminated by the Sun for up to 97 hr. Use of a radiance-enhancement technique permitted unusually low signal-level detection and resulted in the production of images showing high thermal contrast. In agreement with previous studies, these measurements indicate that the crater is warmer than its surroundings during the lunar night, and that the temperature of the thermal anomaly decreases with time, being no longer detectable after new moon. This higher spatial resolution and imaging capability have permitted demonstration that the thermal anomaly is confined to the crater and its outer walls, and that the steeper crater walls facing the Sun prior to local sunset are warmer throughout the cooling phase. These facts are strong evidence that the Tycho anomaly is produced by solar, rather than internal, heat.

Thermoluminescence has been studied by Grumman Aircraft as a possible mechanism for explaining transient bright spots on the Moon. A study of the lunar temperature curve has led to a prediction that thermal glow should be most readily observed at local lunar dawn. In a sample of 97 transient luminous events reported between 1960 and 1965, these events are strongly correlated with dawn, thus confirming the prediction. Thermal glow intensities of possible surface materials have been computed using lunar heating rates and compared with the scattered solar background computed for different times after dawn. The resulting glow intensities exceed the background flux up to several days after dawn.

A simple model of the lunar surface has been developed by Boeing permitting quantitative comparison with temperature variations observed in the 8-to-12 μ band, both during a lunation and a lunar eclipse. The lunar surface is characterized as an evacuated particulate medium

in which radiative heat exchange between solid surfaces plays a decisive role in determining transient temperature changes. An effective microstructure scale of order 0.1 mm is inferred.

Boeing's program of mapping the lunar disk at 10 to 12 μ and at 0.45 μ under illumination for 23 phases from -125° to 135° phase angle has been completed. The contour maps will be published as an atlas in 1967 by NASA. The directionality of lunar infrared emission for a number of Sun angles to the surface has been determined, and is being compared to the in situ infrared measurements obtained from Surveyor 1. The 1000 thermally anomalous "hot spots" discovered by infrared scanning during the December 19, 1964 lunar eclipse showed the greatest concentration in Mare Tranquillitatis; the probability of such a concentration occurring by chance alone is less than 1 in 5000. Other significant concentrations occur in the Kepler-Aristarchus, Guericke and Mösting regions. Infrared eclipse contours have been drawn for overlay onto the LAC charts of the USAF Aeronautical Chart and Information Center.

The Brown Engineering Company, under contract with NASA's Marshall Space Flight Center and in cooperation with the Boeing Scientific Research Laboratories, analysed lunar infrared emission data that was obtained for a lunation by Boeing. It was found that the infrared emission has a definite directional character which seems to be influenced by the direction of the Sun vector. These directional effects bear some similarity to the well known directional properties of the photometric function, although the directionality of the infrared emission is not quite as strong as that of the photometric function.

Surface Structure and Composition. Lunar radar measurements by MIT have continued during 1966 both at Millstone Hill (1295 MHz) and at Haystack (7750 MHz). A rather comprehensive set of observations involving all the Stokes parameters, has been obtained at 1295 MHz for scattering from localized regions of the lunar surface. These results have largely confirmed earlier conclusions, derived from a study of the simple scattering laws, that the diffuse "tail" of the lunar echo results from largely isotropic scattering by irregular, wavelength-sized objects strewn about the lunar surface. Quantitative estimates of the numbers and sizes of these objects obtained from Surveyor 1 photographs show good agreement also with the estimates obtained from the observed scattering. Further, from the close-up photographs which show these objects to lie largely on top of the lunar surface it seems no longer necessary to postulate a surface layer of low dielectric constant as invoked earlier by Hagfors (see COSPAR report, May 1966, p. 173) to explain some of the polarization results, although a surface layer may still be required to reconcile the radar and the radiometric thermal emission data.

Data obtained from the successful landing of Surveyor 1 on the lunar surface has been used by Grumman Aircraft to re-evaluate predictions of the heavier Lunar Module (LM) landing characteristics. Surveyor's data do not indicate a unique lunar soil model, because many configurations with various combinations of friction angle and cohesion equally could satisfy the observations. These possible lunar surface models have been investigated for various LM landing conditions. For predominantly vertical landings, it has been concluded that the lunar surface at the Surveyor 1 site probably is able to absorb the LM's kinetic energy within a fraction of the specified 60-cm maximum penetration. Further studies are being continued for the case where horizontal landing forces are significant and could control the mode of failure of the lunar soil.

A preliminary study of the strength of highly porous vesicular rocks indicates that vesicular rocks with porosity as high as 75% should exhibit sufficient strength for lunar landings. In addition, Grumman completed a study of the thermophysical properties of the lunar surface.

Its objective was to determine if a relationship exists between the bearing strength of the lunar surface and its thermal properties as inferred from observed infrared thermal radiation. It has been found that a definite relation exists between the infrared nighttime temperature and bearing strength. Increasing bearing strength is associated with increasing midnight temperature.

Douglas Missiles and Space Division has been continuing studies reported last year of the ultrahigh vacuum adhesion of silicates. The primary purpose of the study is to obtain quantitative experimental data concerning the ultrahigh vacuum adhesive behavior that may presently exist at the lunar surface. The adhesive behavior was presented in last year's report. During the past year, the behavior of silicate surfaces formed in ultrahigh vacuum was studied, and the adhesion found under this condition was determined to be much larger than that observed for the air-formed surfaces. These results indicate that silicate adhesion can be the major factor in determining the behavior of lunar materials and that its precise role is critically dependent upon the nature of the contacting surfaces.

Experiments concerned with the mechanical properties of probable lunar surface materials have been continued in the three lunar simulation chambers in operation at AFRL. Laboratory tests of the density of rock powders in various size ranges sifted in ultrahigh vacuum, indicate a probable upper density limit of about 1.5 g/cm^3 for the bulk of the lunar surface material, despite high vacuum adhesion of individual particles. The importance of grain shape in controlling density was shown and a figure of about 1.0 g/cm^3 was determined to be a more likely lunar density for use in calculations of bearing strength, thermal conductivity, and dielectric constant than the lower figures associated with the underdense, "fairy castle" model of the lunar surface layer. The AFRL results are in agreement with conclusions drawn from the landing behavior of the Surveyor 1 spacecraft. High- and low-energy proton bombardment of rock and mineral samples has also been carried out to determine the effects of radiation damage on probable lunar surface materials. Experimental evidence has been obtained for proton-induced OH formation, suggesting that such hydroxylation may be an important chemical reaction on the lunar surface.

The reflectance and luminescence of possible lunar materials are being studied by the Space Sciences Department of Douglas Aircraft. Further progress has been made in applying the Fraunhofer line-depth measuring technique to satellite and rocket measurements, and designs of payload experiments are being completed. The proposed lunar measurements emphasize the ultraviolet; however, measurements in the visible also are included, since laboratory studies show the predominant intensity of luminescence is to be found in this region. The measurements will be correlated with past ground observations.

At the Southwest Center for Advanced Studies, Oetking has made a series of light-reflectivity measurements on a variety of samples in a search for materials or surface textures that might reproduce the photometric properties of the lunar surface, particularly the pronounced rise of reflectivity at small phase-angles. It has been found that most terrestrial substances, including standard diffusing surfaces, when observed with an instrument of small aperture show a prominent rise in reflectivity if the direction of observation is within $\pm 5^\circ$ of the direction of the incident light. Experiments show that the height of the intensity peak entails complex interrelations of the particle size, shape, and optical properties of the reflector. The abrupt increase in the brightness of the lunar surface at zero phase may not be an unusual property of the Moon but rather common to most substances. The search for the cause and variations of the intensity peak continues.

Infrared emission spectra of a wide selection of minerals and rocks have been obtained by

AFCRL for comparison with the spectra obtained from the Moon. Samples are also being spectroscopically characterized in the visible and near-infrared both before and after radiation damage.

Selenodesy (Lunar Geodesy). At MIT, fine-scale mapping of selected regions of the lunar surface at 7750 MHz has been accomplished using the Haystack radar. In these studies, delay-Doppler techniques have been used and a surface resolution of between 2 and 4 km has been obtained.

The 61-in. NASA telescope at the Catalina Observatory has been used extensively by LPL in part to obtain new lunar photography for the new Consolidated Lunar Atlas. New films made available by Eastman Kodak Company and Ilford Company of England have been tried experimentally. As a result, Tri-X has gradually been superseded, first by 2475 and later by 4X. A definitive system of recording, cataloging, and indexing the new lunar photography was developed. In addition to the observing book, two reference books have resulted, one arranged chronologically by plate number, giving the necessary observing data, and the other by region on the Moon according to the 44 fields for the visible hemisphere used in the Photographic Lunar Atlas of 1960. As the program developed, more and more photographs per average night were taken, from approximately 100 to roughly 300. Also, the process of visual monitoring was improved. The Consolidated Lunar Atlas, containing 225 photographic sheets, is now expected to be published early in 1967.

Precise measurements have been made of photographs collected by three AFCRL-sponsored solar eclipse expeditions in 1962, 1963, and 1965. This type of photogrammetric analysis uses the solar profile as the reference circle for precise development of the general shape of the Moon. Photographic exposures were made with a 30-cm aperture f/57 mirror which yielded solar images approximately 16.5 cm in diameter. The data derived from these observations compare reasonably well for local irregularities with Watts' Atlas of the Marginal Zone of the Moon. For the general shape, however, a discrepancy occurs for two of the profiles of approximately the same librations. Watts finds a spherical datum satisfactory. The results of the AFCRL analysis indicate the existence of an equatorial bulge at these librations. Data from the two profiles agree in indicating that the lunar equatorial radius is of the order of 5 km greater than the polar radius.

The gravitational field of the Moon as well as its figure have been studied by Boeing using topographic information obtained by applying stereoscopic techniques on photographs obtained by ground-based telescopes. Some of the results obtained are verified by Lunar Orbiter 1 and Luna 10. The zonal harmonics of orders higher than the fourth have also been determined on the basis of the best-figure data.

A program of lunar laser ranging and photographic instrumentation designed to make use of pulses reflected from optical cube corners placed on the lunar surface is being developed by AFCRL. A reduction of sufficient lunar laser observations will provide information such as lunar moment-of-inertia ratios (α , β , γ) accurate to about 1:1000 and would lead to an improved lunar physical ephemeris accurate to about 1 arc sec on the Moon. In addition, two of the geocentric coordinates of the observing site can be established to an accuracy of about 10 m, useful to geodesy.

At NRL a new 20-kW lunar radar has been completed and systematic observations are under way. The observational program is planned to determine topographic heights over a region of approximately $\pm 10^\circ$ selenographic latitude and longitude. This should permit the determination of the lunar radius with an improvement in accuracy by a factor of two. With

this more accurate value of the lunar radius, the uncertainty in mean distance can be reduced to less than a kilometer.

Lunar Atmosphere. The Apollo Lunar Module exhaust is a transient, but potentially large, source of foreign gas for the Moon. Consequently, a simple diffusion model has been formulated by Grumman to determine the spatial and temporal spread of these rocket gases. It has been found that the principal effects of the gases are likely to be noticed within a radius of 300 m of the LM touchdown site. However, rocket gas species would be uniformly distributed around the Moon's surface in a matter of hours for the lighter molecules and in less than a week for the heavier molecules. If the adsorption of gas molecules at the lunar surface is small, the density of these contaminants will remain large enough, i.e., of the order of the ambient lunar atmospheric density, to be detected for expected mission durations. Refinements of this simple model to account for atmospheric effects resulting from lunar-surface temperature variations are in progress. Future plans include extensions of the calculations for consideration of rocket-exhaust gases from the ascent of the lunar module and other Apollo mission contaminant sources.

A joint study of trace contaminants in the lunar module exhaust was conducted by the Earth and Space Sciences Department of the State University of New York at Stony Brook and the Grumman Geo-Astrophysics Section, with the cooperation of NASA/Langley. A mass-spectrometric analysis of samples exposed to LM engine exhaust readily identified N_2 , CO, H_2 and other principal exhaust-gas products. A relatively large peak that was observed at mass 56 has not yet been identified. No evidence was found to indicate the presence of organic substances of mass 65 or greater, a range particularly undesirable with respect to contamination of biological analyses. During 1967, this joint study will be continued using containers of more sophisticated design and more sensitive mass spectrometry to identify organic contaminants that may be present in minute but significant quantities. Experimental work will be undertaken to investigate rates of gas adsorption and desorption from lunar surface materials, and contamination effects of the ascent-stage rocket exhaust on the Apollo Lunar Scientific Experimental Package (ALSEP) will be determined.

Apollo Instrument Plans. After landing on the lunar surface, the Apollo astronauts will make one or more excursions out of their spacecraft. Each excursion will have a maximum duration of 3 hr and will cover areas up to 1000 ft from the spacecraft. First priority will be given to rapid collection of undocumented samples to be returned in case the total excursion cannot be completed. Next, the astronauts will lay out a group of long-lived sensors and instruments. The remainder of the excursion will be devoted to the traverses that comprise the field-geology experiment.

The purpose of the Apollo field-geology experiment is to determine the geologic history of the landing sites and their immediate surroundings through a combination of visual observation, photography, and sampling by the astronauts. As each sample is taken on the traverse, its location will be determined with relation to the spacecraft and the site at which it is taken will be photographed and verbally described by the astronauts. In this manner a complete geologic description of the landing site will be derived. In preparation for this experiment, the astronauts have been given extensive geologic training, including more than 100 hr of classroom lectures and 30 days of field exercises. The flight crews selected for specific Apollo missions will be given individual, intensified training in the tools and instruments developed for the experiment and in the geologic features of their particular landing sites. The astronauts con-

ducting the field-geology experiment will be supplied with a set of geological hand tools that will be packaged in a three-legged tool carrier. The tools include a rock hammer, metal tubes that can be driven into soft soil, a device for determining azimuth and distance from the spacecraft, a small magnifying glass, a sampling scoop, a device for weighing the samples, and a device for taking aseptic samples. The samples will be packed into flexible bags of a special composition to insure against contamination. The bags will then be packed into two large metal containers that are capable of preserving a vacuum of at least 10^{-6} torr. The total return capability is 36 kg which includes the weight of the samples plus the film from the still camera and the weight of the sample containers themselves.

In addition to the hand-held drills being developed for the early Apollo missions to the Moon, larger core drills capable of probing deeper into the lunar subsurface are being considered for late lunar missions. Obtaining subsurface samples by core drilling will provide the most direct information on the location of various geologic formations and rock units as a function of depth, thereby providing data for establishing a lunar stratigraphic sequence. Geochemists and biologists are also anxious to obtain lunar subsurface material from depths where the material is shielded from the effects of bombardment by cosmic-ray nuclei. Northrop and Westinghouse have developed engineering models of lunar drills designed to obtain core material to depths of 30 m or more below the lunar surface.

During 1966, NASA's Manned Spacecraft Center developed the Apollo Lunar Surface Experiments Package (ALSEP) which contains eight experiments to be deployed by the astronauts on the lunar surface which will telemeter data to Earth for a period of 1 year or more. The eight instruments have been divided into two arrays, A and B, each containing five experiments. These arrays will be deployed on separate missions. Array A consists of a three-axis seismometer, a triaxial magnetometer, a solar-wind spectrometer, suprathermal ion detector and cold-cathode ionization gauge. Array B replaces the magnetometer and solar-wind spectrometer with a heat flow experiment, active seismic experiment, and an instrument to measure the charged-particle lunar environment.

Lunar Receiving Laboratory. A Lunar Receiving Laboratory is nearing completion at NASA's Manned Spacecraft Center in Houston for (1) quarantine of returning astronauts and lunar material, (2) the conduct of time-dependent analytical tests on lunar samples before distribution, and (3) the preparation and distribution of the lunar samples to scientific investigators. Scientists in many institutions are preparing techniques, procedures, and analytical methods for examining the samples. One hundred ten scientists from the United States and six other countries have been chosen to conduct a total of 122 experiments with the first samples returned from future Apollo missions to the Moon. Thirty-three of the experiments will be carried out by 27 scientists in laboratories of other countries.

The four major investigative areas are mineralogy and petrology, chemical and isotope analysis, physical properties, and biochemical and organic analysis. Examination of many excellent lunar photographs taken by Surveyor 1 and Orbiters 1 and 2 suggests the possibility of the existence of "organogenic" material on the Moon; particular attention will be given to such determination.

2. MARS

Leighton and Murray of California Institute of Technology have conducted a study of the composition of the Martian polar caps based on a consideration of the heat balance of the planet. This study points strongly toward frozen CO_2 as the dominant substance comprising the Martian polar caps. The study investigated the expected diurnal and annual temperature variations at various latitudes, using a thermal model of the Martian surface in which each surface element was treated as a horizontal plane, at some instantaneous temperature T_1 , which absorbed a fraction F of the incident solar radiation, emitted blackbody radiation at temperature T_1 with an emissivity E , exchanged heat with underlying layers by thermal conduction (with constant conductivity), and absorbed or released latent heat if a condensed volatile was present. Radiative thermal exchange with the atmosphere was assumed negligible except insofar as the atmosphere might affect E by blocking certain wavelengths emitted by the surface. Horizontal heat transport by wind was also neglected, although some form of planetary circulation is presumed to replenish condensed CO_2 and H_2O .

The main conclusions indicated by this study are: (1) The atmosphere and frost caps of Mars represent a single system with CO_2 as the only active phase; (2) The appearance and disappearance of the polar caps are adequately explained on the presumption that they are composed almost entirely of solid CO_2 with perhaps an occasional thin coating of water-ice; (3) If the currently reported water-vapor observations are correct, water-ice permafrost probably exists under large regions of the planet at polar and temperate latitudes; (4) The geochemically anomalous enrichment of CO_2 relative to N_2 in the present Martian atmosphere may be a result of selective trapping of CO_2 in the solid phase at and under the surface; and (5) If the basic evaporation and condensation mechanisms for CO_2 and H_2O assumed in this study are correct, the possible migration of volatile organic compounds away from the warm temperate regions of the planet and their possible accumulation in the polar regions need to be carefully considered.

Connes and Kaplan reported new absorption bands in the near-infrared (1.44 to 1.75μ) by Michelson-type interferometry (Fourier spectroscopy) techniques. The bands are tentatively identified as due in part to gases in the Martian atmosphere: curve-fitting suggests similarity to CH_3F .

Studies on Mars by Rea and O'Leary at Berkeley have included the effect of topography in influencing the depth of the polar ice cap, assumed to be solid CO_2 . A simple calculation indicates the Mountains of Mitchel are in fact depressions 6 to 9 km lower than the surroundings. This result, together with similar considerations on the formation of temporary bright patches overlying Martian light areas, supports the view that such areas are depressed and the dark areas elevated.

A comprehensive model of the surface environment of Mars has been developed at SAO and Harvard by Sagan and Pollack. They conclude that the reasons for elevations being colder on Earth do not apply to Mars and that the seasonal growth and recession of the Martian polar caps suggest that the dark areas are highlands. Radar-Doppler spectra of Mars obtained from the 1963 and 1965 oppositions at the Goldstone tracking facility were analysed in conjunction with Goldstein of JPL and, both from the total power as a function of longitude and from the details of the Doppler spectra, it was concluded that Martian dark areas are at higher elevations than the bright areas. Regions undergoing marked secular changes have shallow slopes, suggesting that the secular changes are due to drifting dust. Major dark areas such as Syrtis

Major may be 10 to 15 km above the surrounding deserts. Such differences in elevation may explain the discrepancy in results concerning Martian pressures obtained by infrared spectrometric and Mariner 4 occultation experiments, since the bright areas are more than a scale height below the dark areas, and the occultation experiment is strongly biased toward elevations. The results may also help explain the discrepancy between the optical and dynamical oblateness of Mars. From radar and Mariner 4 data it is concluded that the "canals" may be ridges running through the Martian lowlands, possibly analogous to the terrestrial oceanic-ridge system.

These elevation differences then permit the construction of an inorganic model of Martian seasonal phenomena in which smaller, more highly reflecting particles are blown off the highlands during spring and then redistributed back on to the highlands by the different prevailing winds of late fall and winter. The particle sizes implied are just those derived independently from photometric and polarimetric observations and the wind velocities are in agreement with meteorological theory. The photometric and polarimetric properties of both the bright and dark areas have been reproduced, assuming that bright and dark areas are both covered with goethite (hydrated iron oxide) but that more finely pulverized dust covers the bright areas. The intrinsic contrast between bright and dark areas is then predicted to become very small, shortward of 4500 Å; it is suggested that the Martian "blue haze" is a surface effect and not an atmospheric phenomenon. Sagan argues that the large amounts of iron deduced for the Martian surface are chiefly a consequence of the absence of core formation and of meteoritic infall on Mars.

Sagan and his colleagues consider that the possibility that Martian seasonal changes are not due to vegetation is not a major argument against the possibility of life on Mars. They have found it very difficult to detect seasonal contrast variations in terrestrial vegetation using the Tiros and Nimbus meteorological satellites and have concluded that a few thousand photographs of the Earth would be required to detect even intelligent life on our planet, if the several-kilometer resolution obtained by Mariner 4 on Mars were used. Several orders of magnitude better resolution would be required to detect lower forms of life by photographic reconnaissance.

The Space Sciences Department of Douglas Aircraft is studying the chemistry of the Martian surface. In previous work by Fish, the conclusion was reached that goethite is unstable on the Martian surface. This conclusion was strengthened by recently published experimental data. The thermodynamic stabilities of other common hydrates and carbonates are being calculated from available thermodynamic data. This will allow some predictions to be made as to which minerals are likely to be present on Mars. It will also constitute a first step in the study of chemical interactions of the atmosphere and surface of a planet with a thin atmosphere and no surficial liquid water.

A study of the Martian surface carried out by Binder and Cruikshank of the University of Arizona's Lunar and Planetary Laboratory suggests that the Martian deserts consist of rock outcrops coated with a hard surface stain of limonite.

Extensive measurements of the reflectance and polarization properties of pulverized limonite were made by General Electric at a number of illumination angles and over a hemisphere of observed directions. These data were used to predict the distribution of intensity and polarization at wavelengths of 4920 Å and 6430 Å over the Martian disk assuming a limonite surface and Rayleigh scattering from several model atmospheres. Although the overall albedo and polarization properties deduced from this model for the Martian disk agree well with astronomical values, the photoelectric limb curves of Koval are not reproduced. Experimentally it is

observed that the directional reflectance of limonite possesses a maximum in the backward direction, in which relative intensity increases at low illumination angles. This leads to the absence of significant limb darkening in the visible, whereas Koval's results show limb darkening more characteristic of a Lambert surface. Directional reflectance measurements on a number of other powdered surfaces show backward directional maxima qualitatively similar to that for pulverized limonite so that it is unlikely that the limb-darkening is related to a Lambert-type solid surface. The failure of the limonite model to reproduce the limb-darkening curves is therefore not interpreted as weakening the case for limonite as a constituent of the Martian surface but is believed more likely attributable to non-Rayleigh processes in the Martian atmosphere which become important for oblique transmission paths through the atmosphere.

The seasonal color change observed for Mars remains an enigma. One hypothesis is that the change is chemical, involving changing atmospheric composition and the surface mineral. Brucite, a form of serpentine that also is found in meteorites, is known to change color from green to yellowish upon exposure to carbon dioxide and some water vapor. An investigation is under way at Grumman Aircraft to demonstrate the reversibility of color change of brucite under a simulated, varying Martian environment. The results of this project could provide a better understanding of Martian phenomena and guide future site selection and scientific payload decisions.

Calculations have been made by Spergel of Grumman Research of the solar-flare-induced neutron intensity as a function of depth, both in the Martian atmosphere and beneath the Martian surface, corresponding to two classes of neutron transport, near-thermal diffusion, and fast-neutron diffusion. For small neutron-attenuation lengths (near-thermal diffusion), a marked structure in the neutron-intensity profile as a function of depth is seen. For the larger attenuation lengths, there is a sizable increase in the neutron levels and a smoothing out of the profiles. An effort is presently being made to relate neutron-attenuation lengths used for the Martian atmosphere and surface materials to results from experimental and theoretical investigations of the Earth's upper atmosphere. Results to date indicate that neutron-intensity levels in the Martian surface would not be hazardous to man.

A model Martian atmosphere based on equations of photochemical and diffusive steady state has been simulated by a computer at Boeing. The equations include nonreactive quenching processes, the photoproduction of $O(^1D)$ atoms by solar ultraviolet between 1300 and 1750 Å, and its subsequent reaction with CO_2 to form CO and O_2 . The computed enhancement of Mars' total CO content is 10 times that which results when the chemistry of $O(^1D)$ is excluded. Since the permanent dipole moment of CO makes it an efficient infrared radiator, and therefore an effective cooling agent, and since all calculations show very low ratios of CO_2/O and O_2/O at 125 km, these studies support a low-temperature model for the Martian upper atmosphere.

At Kitt Peak National Observatory a Monte Carlo technique was used to study the escape of light gases from planetary atmospheres. Results were applied to the escape of hydrogen and helium from the Earth's atmosphere. This work has confirmed the accuracy of the simple formulae devised by Jeans and the early kineticists. A detailed description of the complex physical and chemical processes that determine the thermal structure of a planetary atmosphere is also in progress. The research is directed mainly towards Martian problems but has also been applied, for a check, to the Earth's atmosphere above 60 km. This treatment accounts for the detailed thermal structure of the Earth's atmosphere and should also provide satisfactory results for Mars. It has been extended to an evolutionary study of the atmosphere of Mercury.

A new laboratory facility has been constructed at Grumman to permit simulation of boundary layer processes in planetary atmospheres. Initially, a simple 1.2-m diameter by 1.2-m high plexiglass chamber is being used to study convective motion from a simulated heated planetary surface. This facility is being used in preliminary tests to examine the initiating mechanism for observed Martian yellow-cloud formations, believed indicative of high velocity dust storms. Such storms could create hazardous conditions for spacecraft landers. The second phase of this program will involve the use of a chamber capable of subatmospheric pressures, on the order of 10 mm Hg (i.e., simulating Martian surface pressure), employing gases believed representative of the Martian atmosphere (e.g., carbon dioxide). In addition to extending the current investigation of surface-material transport, it is planned to test the theory recently advanced by Goody of Harvard College Observatory concerning heating of the Martian atmosphere by radiation.

The study of dust devils as a possible cause of the Martian yellow clouds is also being conducted in the Douglas Aircraft Space Sciences Department. The purpose of this study is to determine the conditions that favor dust-devil formation and to ascertain if these conditions can be met on Mars. A theoretical model for dust-devil generation that agrees fairly well with the sparse field observations has been formulated by Ryan. Additional field data have been collected during the past year.

3. VENUS

Echo-delay and Doppler radar measurements for Venus were made from the beginning of 1966 through April 7 by MIT using the Millstone radar at 1295 MHz. Since late October 1966, a new and much more sensitive radar system at the Haystack facility, operating at 7840 MHz, has been available for observing both Mercury and Venus. These measurements, together with others of comparable accuracy obtained during the summer from the Arecibo Ionospheric Observatory, have been reduced to obtain improved estimates of the orbital elements, masses, and radii of the planets Mercury, Venus, and Earth. In addition, the astronomical unit has been further refined to 499.00479 ± 0.00005 sec, and the Earth-Moon mass ratio to 81.303 ± 0.005 . Radii of 2435 ± 5 km for Mercury and 6055 ± 5 km for Venus have been obtained from the radar observations.

A number of regions of anomalous radar reflecting properties, many corresponding in position to locations reported earlier by JPL, were found on Venus during the winter observations at the Millstone radar. The Haystack observations at 7750 and 7840 MHz were distinguished chiefly by the relatively low radar cross section observed. The low value is generally attributed to Cytherean atmosphere absorption. Some variability in cross section has been observed, the source of which is not yet understood.

Radar studies of Venus, concurrent with those from MIT's Lincoln Laboratory, but employing a lower exploring frequency, were obtained by ITSA at Jicamarca in early 1966. These results should reveal significant information about the interplanetary medium. During the same period, radar studies of the lunar surface were also made.

The Arecibo planetary radar system has been extensively used by Cornell for making high-resolution studies of the radar backscattering characteristics of Venus and Mercury in particular. A surface resolution on the order of 50×50 km has been achieved using the simultaneous range-Doppler mapping techniques. Both planets exhibit regions of anomalously high power

reflectivity apparently caused by local variations in surface roughness. Most of the anomalous regions appear to be of "continental" size whose shapes can be mapped in planetocentric coordinates.

Arecibo observations of Venus at 70 cm indicate that average surface roughness of the planet is smaller by a factor of 2 or 3 than that of the Moon. Studies of all the radar-backscatter observations of Venus indicate that this smoothness relative to the Moon is present for a range of wavelengths from 3.6 to 70 cm. The radar observations over this wavelength range strongly suggest a high atmospheric opacity at the short cm wavelengths (on the order of unity) with an inverse-square wavelength opacity law. The cm opacities have a very strong effect on possible Cytherean model atmospheres.

The passive microwave spectrum of Venus was measured by Griffith, Thornton and Welch at Berkeley at seven frequencies in the interval 18 GHz to 36 GHz in July 1964 shortly after inferior conjunction. The resulting spectrum shows a fairly smooth but rapid decrease in the planet's brightness toward the high frequencies. The measurements are compared with the spectra of several model atmospheres that contain CO₂, N₂, water vapor, liquid-water clouds, and high dust or ice clouds. None of the model spectra exactly fits all the present measurements. A best fit for the model in which absorption is due to CO₂ and N₂ requires a surface pressure of about 200 atm. A best fit for the model that contains, in addition, water vapor and liquid-water clouds requires about 12 g/cm² of the vapor and 0.06 g/cm² of liquid-water clouds at 240°K. The nicest agreement is provided by a model that contains scattering particles. For dust particles of mean diameter 0.3 mm and dielectric constant 5, the required number of particles is $2.5 \times 10^{16}/\text{cm}^2$.

At Kitt Peak, a Doppler-shifted water-vapor line was observed in the spectrum of Venus with the 60-in. solar telescope.

Efforts were made by the Space Science Laboratory at Berkeley to observe a Cytherean halo comparable to the halo about the Sun commonly observed from Earth. Observations were made on the 16-in. telescope at Kitt Peak to detect intensity and color changes at phase angles where the halo is calculated to occur for hexagonal ice particles. Polarimetric data obtained by Dollfus in France were also included in the study. Marginal evidence for the existence of the halo was obtained and a rough estimate of a 5% concentration of hexagonal water-ice crystals in the Cytherean clouds was derived by O'Leary. In view of the importance of this tentative identification, plans have been made to obtain additional more refined data at the next opportunity.

Additional work on Venus by Rea of Berkeley has been the re-examination of all evidence for water-ice or liquid-water clouds. In contrast to the beliefs expressed recently in the literature by other authors, Rea does not believe there is good infrared evidence that the majority of the scattering centers are water—solid or liquid. It is his opinion that the composition of the bulk of the Cytherean scatterers is still unknown.

Spectral characteristics of water frost and of carbon dioxide "frost" were obtained in NBS measurements by Keegan and Weidner. The results should be useful in studies of the Cytherean cloud cover, which may be composed of crystals of one or of both of these substances. The laboratory spectra will be checked against infrared spectra to be obtained from Venus in future space probes. They may also aid in climatic studies of the planet. For example, it is not now known why the clouds surrounding Venus apparently remain at the same temperature, both on the bright side of the cloud cover reflecting the Sun's rays, and on the dark side away from these rays.

The Douglas Aircraft Space Sciences Department is still working on a study to ascertain

the merit of the speculation that the microwave emission from Venus might be partly non-thermal in origin. Investigations have indicated that cloud processes and possible rainfall on Venus are unlikely to contribute significantly to the observed microwave emission. Lightning discharges and processes associated with blowing dust are currently being considered.

4. OTHER PLANETS

Jupiter. The 61-in. NASA telescope at the LPL Catalina Observatory has been used in a continuing program of planetary photography, with special emphasis on Jupiter, and for spectral studies. Design of the ten-channel spectrometer for use with the telescope was begun under the supervision of Binder and Cruikshank. Completion of the instrument is expected in early 1967. Improved spectra of Jupiter in the region 1 to $2.5\ \mu$ were taken by Kuiper with the 84-in. Kitt Peak telescope, using the 12-cm beam ir spectrometer. Binder and Cruikshank continued to investigate the presence of atmospheres in satellites of Jovian planets. Observations of Titan were made and a report on the Jovian satellites was published.

A series of color photographs of Jupiter was obtained with the 155-cm telescope, as was nearly continuous photography of Saturn's rings as they passed through the nodes with the Earth in October and December 1966. Much high-quality lunar photography was obtained with this telescope, resolutions having been obtained to 0.15 arc sec for many areas.

Brightness temperatures at $22\ \mu$ have now been obtained for Mercury, Venus, Mars, Jupiter, Saturn, Uranus, and the Galilean satellites by Low of LPL. Narrowband observations of Jupiter at 13.0, 18.9, and $24.5\ \mu$ indicate an increase of T_B with λ , consistent with NH_3 as the source of opacity and internal energy of 3 to 4 times the solar input. This energy is probably generated gravitationally and indicates that Jupiter is contracting at the rate of about 1 mm/year. A similar result is found for Saturn but not for Uranus. High resolution scans of Jupiter were made at $22\ \mu$ with the 61-in. NASA telescope. A hot equatorial band was discovered which may be caused by vertical lifting near the equator and downward flow at the poles.

Mercury. The polarimetric evidence for an atmosphere on Mercury has been re-examined by the Space Sciences Laboratory, Berkeley, with negative results. An examination of existing observational data of Mercury in conjunction with recent lunar and laboratory data led to the conclusion that there is no polarimetric evidence for a Mercurian atmosphere. A rough upper limit of 1 mb was imposed on the pressure.

Improved spectra of Mercury were obtained by LPL showing the $1.6\text{-}\mu$ bands of CO_2 to possess no planetary component (only telluric) contrary to a report by Moroz.

Miscellaneous. Observations of radio emission from Jupiter, Saturn, and Mercury at 1.53-cm wavelength are reported by Welch, Thornton and Lohman at Berkeley. The disk temperature of Saturn was found to be 0.94 times that of Jupiter at this wavelength. Mercury, observed at an average phase angle of 125° , was found to have a disk temperature three times that of Jupiter. With Jupiter's disk temperature assumed to be 150°K at this wavelength, the temperatures of Saturn and Mercury are 141°K and 450°K , respectively. The similarity in emission from Jupiter and Saturn at this wavelength can be explained if one supposes that ammonia gas is the chief source of microwave thermal radiation from both planets (due to the ammonia absorption band centered at 1.28 cm) and that the gas is saturated near the cloud tops of both

planets. The possibility that emission from Saturn's rings may contribute to the radio disk temperature of Saturn has been briefly considered. If the particles are many centimeters in diameter and perfectly absorbing, the rings contribute about 25° K to the disk temperature. On the other hand, if their mean radius is about 300μ , a probable size obtained by Franklin and Cook, their microwave-extinction cross section is small and they will not emit significant microwave energy. The high disk temperature of Mercury at large phase angles is in agreement with the observations of Howard, Barrett, and Haddock at 3.75 cm and Kellerman at 11 cm. With the recent radar determination that Mercury does not keep the same face to the Sun, these results can be understood if one supposes that the microwave emission from Mercury is like that from the Moon.

In conjunction with Lippincott of the University of Maryland, and Eck and Dayhoff of the National Biomedical Research Foundation, Sagan of Harvard - SAO has made a computer analysis of the expected thermodynamic equilibrium composition of the atmospheres of Earth, Mars, Venus, and Jupiter. They find that except for trace compounds produced by biological activity, lightning, radiation, and vulcanism, the terrestrial atmosphere considered as a closed system is near thermodynamic equilibrium. The atmosphere of Venus is inconsistent with the possibility of hydrocarbons or other organic molecules either on the surface or in the clouds. For Mars, Venus and Jupiter there are no molecular species of large predicted equilibrium abundances nor of spectroscopically accessible absorption features that have not already been identified. However, at high temperatures such as would be produced by lightning discharges, simple hydrocarbons and cyanides, substituted polycyclic aromatics, and a variety of nitrogen compounds would be expected on Jupiter. Some of these compounds are brightly colored, and may contribute to the observed variable colorations of the bands, belts, and spots of Jupiter.

5. METEORITES

The eight-station system of the SAO Radio Meteor Project near Havana, Illinois, continued routine observations, with approximately 24 hr of operation in each alternate week plus additional time for streams. Peak transmitter power is normally 2 MW. Meteor counts at four sensitivity levels indicate that the cumulative number N of meteors detected above mass m is proportional to $m^{-1.0}$ in the mass range 10^{-4} to $10^{-5.5}$ g. The relative space density of radio meteors in the mass range 10^{-2} to 10^{-6} g has been computed, using an approximate correction for orbits not observable at the Earth. Toward the Sun, the density varies as the -0.8 to -1.0 power of the radius vector; outward from the Earth, the density varies as the -1.5 to -2.5 power.

At NASA's Marshall Space Flight Center, statistical results have been used as a basis for decision between Öpik's and Verniani's relations between luminous efficiency and velocity. This was done by using a weighting function with Hawkins' and Southworth's random sample of 285 sporadic photographic meteors. Each of the sample sets of mass values for the two luminous efficiency formulations was ranked with respect to particle mass and partitioned at a mass value giving subsets of comparable statistical weight. The two subsets of the sample gave markedly different distributions of various parameters, such as velocity and eccentricity. The numerical values of linear correlation by which particle mass is related to other parameters are substantiated by this method. The results show a higher plausibility for Öpik's relations.

During 1966, AFCRL concentrated on two major problems in the area of meteorite studies. The first of these was the detailed investigation of a group of unequilibrated ordinary chondrites that are thought to represent the most primitive examples of common meteoritic matter. The significance of these meteorites was noted at AFCRL during 1965 and the recent work succeeded in delineating the known number of such meteorites (about two dozen) and demonstrating that there is an unbroken continuum of chemical, mineralogic, and physical properties between these primitive chondritic meteorites and the most highly metamorphosed chondrites. One very important consequence of this study was the development of a classification of the chondrites that reliably characterizes their mineralogic properties. The other major study concentrated on those chondrites that are highly metamorphosed. Microprobe analyses of coexisting mineral phases allowed distribution coefficients of iron and magnesium among the phases to be calculated. Because such distributions are temperature-dependent, it was possible to estimate the temperature at which these meteorites attained equilibrium. The resulting estimate ($\sim 800^{\circ}\text{C} \pm 50^{\circ}\text{C}$) is much lower than previous estimates.

Seven examples of interbrecciation between diverse types of carbonaceous and noncarbonaceous meteorites have supported the theory of common parent-body origin of all types of meteorites. The study, made by the University of Miami's Institute of Molecular Biology, furnished additional evidence in favor of the hypothesis that these are produced through a process of redistribution of volatiles along a thermal gradient. Interpretation of lunar photographs resulted in the conclusion that the majority of the meteorites are of extralunar origin.

Studies were made by MIT of the forces influencing motion of small dust particles orbiting near the Earth and in interplanetary space. The studies consisted of four primary investigations: (1) forces perturbing dust-particle motion, (2) gravitational focusing and Jacobi capture, (3) lunar ejecta, and (4) sunlight-pressure and air-drag capture.

Life Sciences

1. EFFECTS OF THE SPACE ENVIRONMENT ON MAN AND OTHER TERRESTRIAL ORGANISMS

Synergism of Space Flight and Space Environmental Factors. Experiments have been conducted at the Lawrence Radiation Laboratory to test whether chromosome breaks during space flight could be due to synergism of radiation effects and vibration. Working with mammalian cells in culture, the experimenters found no synergism for cell survival at 100 or 1000 cps even at quite high sound intensities. At ultrasonic frequency of about 10^6 cycles, a very weak ultrasound produced marked synergistic effects with radiation both on cell survival and on chromosome breaks. The ultrasound by itself, at this intensity, had no demonstrable effects.

In an experiment on the effects of hypoxia and radiation, Tobias at Berkeley obtained results indicating a certain degree of synergism. This effect, in female beagle dogs, was brought about by a relatively uniform whole-body dose of 200 rads from the 730-MeV proton beam of the 184-in. cyclotron (degraded to a residual energy of 270 MeV). Immediately following the irradiation, the animals were subjected to a simulated altitude of 18,000 ft for a period of almost 2 months. About 6 days after the radiation exposure, the animals were unable to compensate for partial anoxia. Changes occurred in the blood chemistry, blood counts, iron kinetics, bone-marrow differentiation, and total body volumes.

The parasitic wasp, *Habrobracon*, was utilized by Grosch at North Carolina State University, Raleigh, to determine the effects on egg production of radiation (^{60}Co gamma source) in combination with vibration (160 cps for 1 hr). Synergism of these two stresses occurred between 6 to 10 days following exposure to 1000 r + vibration, 2000 r + vibration, and 4000 r + vibration. In combination with ionizing radiation, vibration resulted in curves which lie above those for the same radiation dose administered separately.

Vibration effects only were studied in *Tradescantia* buds exposed to 300 to 3500 cps and 5 to 20 g for 3 to 15 min by Beischer and Knepton at the Naval Aerospace Medical Laboratories, Pensacola. There was no significant difference of chromosomal aberrations from

the controls. The only aberration (0.18%) that was found among both groups was the spherical fragment type.

Radiation. Protection against radiation has been reported to occur during hibernation, but the animal is protected only so long as it remains in hibernal torpor. In a series of experiments, levels of whole-body irradiation by ^{60}Co ranged from 1000 to 3000 r. There was a significant decrease in mortality of ground squirrels that were irradiated during hibernation. Many of the treated animals survived for several months, gained weight, and behaved in every respect like the non-irradiated controls. The biochemical mechanisms underlying this physiologic response are under investigation.

McDonnell Company and Washington University School of Medicine participated in a joint study on the effects of 6.0-MeV electrons on the skin of white miniature swine. Erythema was established as an objective endpoint; however, delayed appearance of this evidence of damage (linearly related to total dose delivered) resulted in an investigation of methods to detect radiation damage before erythema appears. Dye accumulation in the injured skin and studies using an isotope of oxygen have merit as research tools for such assessment. In the experimental animal studied, the erythema threshold was established as 600 to 800 rads of 6.0-MeV electrons, dependent upon the size of the skin area irradiated.

An improved system for measuring tissue-equivalent radiation doses has been conceived by Northrop Corporation for use in monitoring the radiation received by man during space flight. The key element of the system is a sensor consisting of a number of 100- μ plastic scintillator spheres bonded to a lucite light-pipe connected to a photomultiplier tube. Techniques have been developed for eliminating the non-linear response of organic scintillators to different types of particles. This instrument has many advantages over ion chamber instruments, including (1) measurements of absorbed dose in a detector that approaches cellular size, (2) negligible dose-gradient through the detector with minimum perturbation of the tissue-equivalent sample, and (3) excellent resolution and gain stability. Analysis has shown the feasibility of measuring the absorbed dose-distribution spectrum from 0.4 to >300 keV/ μ with a single sensor.

Weightlessness. White and co-workers at Douglas Aircraft Company's Advanced Biotechnology Department are conducting a study to assess the relative physiological responses produced by two zero-gravity analogs, bedrest and immersion. Ten subjects, each serving as his own control, were exposed to alternate 10-day periods of bedrest and fluid-silicone immersion. Functional, diagnostic, and monitoring tests performed before, during, and after the test periods were used to assess changes. Slightly greater deconditioning was produced by immersion than by bedrest. In a second study, the influence of periodic centrifugation on the physiological disturbances associated with 10 days of bedrest was examined. It was found that short periods of centrifugation four times a day largely alleviated the expected cardiovascular deterioration produced by bedrest.

Research under the direction of Graybiel at the Naval Aerospace Medical Institute, Pensacola, is concerned with the problem of man's gravito-inertial-force environment in space flight. A rather broad program involves studies of vestibular mechanisms, observations in parabolic flight, and the side effects of exposure in a rotating environment.

In previous years, experiments in the Pensacola Slow Rotation Room (SRR) dealing with functional disturbances of vestibular mechanisms have positioned the subject's long axis, when standing upright, parallel or not far from parallel to the axis of rotation. In an orbiting,

rotating spacecraft, however, the astronaut when upright will be oriented at right angles to the axis of rotation. To simulate this orientation in the SRR, it was necessary to provide reasonably good living and working conditions while the subjects were in the Earth-horizontal axis. This was done by means of an articulated fiberglass body-mold and an airbearing support. The subjects were upright with respect to the wall about 7 hr a day and the remainder of the time were recumbent, except for a total period of 10 min in 24 hr.

A study of motion sickness was occasioned by symptoms manifested by persons exposed in the SRR to varying speeds and rates of onset of rotation. The findings have bearing on nearly every major aspect of motion sickness and have permitted a ranking of antimotion-sickness drugs in terms of their effectiveness in altering susceptibility to symptoms in the SRR. The findings can be used as a criterion reference for comparison with analogous findings in other force environments.

Cardiovascular Problems. Pace and co-workers at the University of California, Berkeley, have obtained baseline data on primates for current and future space-bioscience missions by implanting electromagnetic flow probes in the aorta. In Macaca nemestrina a probe was attached on the ascending aorta in close proximity to the heart. In one monkey, the flow probe remained functional for a period of 29 days post-operatively; in a second, the flow probe functioned for over 60 days. The lowest flow-rates occurred during the early morning hours, while peak flow-rates were noted in the late afternoon, demonstrating a diurnal pattern of blood flow. These preliminary data indicate that flow probes may be used in studying the cardiovascular system for many weeks in the unanesthetized primate exposed to varying environmental situations. An extension of this study, designed to determine the effects of catecholamines, revealed that physiologically the cardiovascular system of the M. nemestrina reacts to epinephrine and norepinephrine in a fashion identical to man.

Murray, Krog, Carlson, and Bowers of the Universities of Indiana and Kentucky, have been investigating the value of lower body negative pressure as a provocative test for the circulatory system. This concept, introduced by Greenfield, has been developed for the lower extremities. The test includes plethysmographic measurements on the toe, leg, finger, and arm; changing the center gravity of the body by means of head- and foot-weighting; and applying negative pressure to the lower half of the body. Derived data include heart rate, blood flow and capillary filtration. Apparatus consists of a shell covering the body from the waist down with an inflatable gasket seal around the waist. The bed is suspended on each end by cables from a differential transformer so that the weight at head and foot can be determined. Fluid shift (weight change and limb-volume change) is determined for 5-min periods at -10, -20, and -40 mm Hg in ascending and descending order. The test has advantages over the tilt-table test: The mid-body seal does not affect venous return through the vena cava and the increase in transmural pressure is accomplished without increased venous pressure.

Because the physiological effects of the application of negative pressure to the lower body (LBNP) have been attributed to a diminished effect blood volume, Murray and co-workers also studied the cumulative effects of venesection and LBNP on the circulation. Following the placement of an indwelling venous needle, each of four experienced subjects was exposed to negative pressure (0 to 40 mm Hg) applied to the lower body in seven 10-mm steps for intervals of 5 min each. Following this test, 500 ml of blood were withdrawn and the test repeated. Another identical series of paired LBNP exposures was carried out, but without venesection. Measurements were made of heart rate; blood pressure; calf and forearm volume and forearm

blood flow by venous occlusion plethysmography; plasma volume; hemoglobin; hematocrit and plasma proteins. Results demonstrate that this regimen of LBNP application provides a significant circulatory stress, and suggest that approximately 1 liter of blood is lost from the effective circulation with the use of this negative-pressure technique.

Respiratory Physiology. To separate surface heat-conductivity factors from possible biochemical and pharmacologic influences of helium, a series of human tests was conducted by Weiff and Hyatt at Ohio State University. The subject breathed either air or helium-oxygen (79:21%) while the body was exposed either to air or to a helium-oxygen (79:21%) atmosphere at 30°C. The results indicate, at least for 30°C, that the major if not the sole effect of helium is heat loss from the skin. When helium-oxygen was in contact with the body surface, regardless of whether air or helium-oxygen was breathed, skin temperatures were lower than in air contact. There was no difference in oxygen uptake. This suggests that the human subject compensates for lowered skin temperature by vasoconstriction rather than by increased metabolism.

Exposure of rats to a high oxygen - low pressure environment (100% oxygen, 5 psia) initially produced symptoms of marginal oxygen toxicity in experiments conducted by Jordan at the University of Oklahoma City. The body weights of the experimental animals were somewhat greater after 12 weeks of continuous exposure than comparable control animals. The greater carbohydrate content of both tissues and carcasses after 12 weeks of exposure, together with a smaller amount of lipid, suggest a difference in the energy source utilized by the experimental animals. Serum and tissue cholesterol (from precursor ¹⁴C-acetate) concentrations increased as a function of the period of exposure to the test environment. Although the concentration had returned to normal values in the liver and kidney after 12 weeks of exposure, heart-cholesterol concentrations were still high. These data suggest the possibility of atherosclerosis in susceptible animals and pose an even more significant question in man.

Behavioral Biology. The fundamental biological question of the nature and causal factors of sleep is being brought more sharply into focus by the requirements of space flight. In studies on the problems of sleep, wakefulness, dreams, and memory, the significance of various stages of sleep has been determined, particularly that stage associated with rapid eye movements (REM). Investigators at the University of California, Los Angeles, have established a consistent correlation between antidiuretic hormone release and the onset of REM sleep, and have demonstrated other neuroendocrine and metabolic changes associated with the onset of this particular type of normal sleep.

The external and internal causal and controlling factors involved in sleep, and other rhythms of approximately 24-hr period remain a topic of both fundamental and applied interest to space biology. At the Max-Planck Institute for Behavioral Physiology, subjects isolated in underground bunkers were subjected to changes in dark and (reciprocally) light periods analogous to aircraft flights in easterly and westerly directions. Re-adaptation (re-entrainment) following shortening of dark time (easterly flight) occurred immediately, in contrast with the longer time required for re-entrainment following "flight" in the westerly direction.

University of Minnesota investigators have applied advanced techniques of computer analysis to circadian rhythm data obtained in France, where two adult human subjects volunteered to spend 3 to 4 months in underground caves in the absence of known time-cues. Artificial sources of heat and light were turned on at each awakening and were turned off upon retiring.

Results of routine clinical and biological examinations indicate that the stay underground was well tolerated by both subjects. The results support the view that the behavioral effects of early sensory restriction are due to a failure to filter out irrelevant information on the basis of prior experience, thereby producing excessive arousal of the central nervous system and a disruption of perceptual discrimination and adaptive responses.

Studies at the University of Kentucky have dealt with the role of gravitational forces on the control of behavior. Monkeys operated a level which controlled the rate of rotation of an automatically programmed centrifuge. Pressing the lever reduced the amount of artificial gravity by reducing the rate of rotation. Avoidance of g levels above normal Earth gravity was demonstrated over periods of many weeks. Extension of these studies to gravity levels below 1 g requires inflight experimentation.

2. LIFE SUPPORT

Nutrition and Energy Expenditure. Crew energy-expenditure requirements of space flight, both intra- and extravehicular, are vital to system planning because of their direct influence upon oxygen stores, carbon-dioxide and water removal, suit ventilation and task assignments. Recent experience with extravehicular activity in the Gemini flights has served to emphasize the need for better information in this area. A continuing research program has been initiated by the McDonnell Company to (1) evaluate which secondary methods of estimating energy expenditure offer the simplest approach to inflight measurements and (2) develop and compare with classical techniques unique methods of indirect calorimetry applicable to space flight. Both shirtsleeve and pressure-suit (vented or inflated) data are being gathered. The influence of heat stress, CO₂ build-up, and 100%-oxygen breathing are among the variables being studied. Direct and indirect results of the study should be applicable to any manned system, particularly as they relate to hard-suit activities in a weightless environment.

A space-physiology project on protein requirements is being conducted by Galloway and Morgan at Berkeley to determine the minimum amount of protein necessary to maintain fully fit men with respect to a variety of biochemical, physiological, motor, and psychological criteria. The primary technique used is the determination of external metabolic balances, but the studies are unique in that all routes of nitrogen loss from the body have been measured: urinary, integumentary, and solid-waste and gaseous losses from the intestinal tract. In addition to investigations of nitrogen requirements, extensive studies of body composition, mineral balance, blood chemistry, physiological responses, psychological alterations, and sociological responses have been carried out. Experiments of 60 to 100 days' duration were designed to test the hypothesis that the amount of nitrogen excreted during the consumption of a protein-free but otherwise nutritionally adequate diet predicts accurately an individual's minimal protein need. Adding the amount of nitrogen to the diet as high-quality protein should not augment urinary output and should thus promote nitrogen balance. Results of the studies generally support the hypothesis. However, when high-quality protein in an amount equal to endogenous loss was fed, nitrogen equilibrium was approached in most subjects but achieved in only a few. Minimum protein requirement varied from 4.5 to 6.5 g of nitrogen per day and was more dominantly related to utilization of dietary protein than to variance in endogenous excretion or body mass.

Another finding is that the amount of calcium lost in the urine is directly proportional to the dietary protein intake. At low protein levels the urinary calcium loss is slight; as dietary protein increases the calcium loss increases. Urinary phosphorus excretion, however, varies inversely with dietary protein level. Studies have been carried out on the effects of the alteration of energy intake and work output on these variables. Results have demonstrated that a combined chair- and bedrest regimen has little effect on nitrogen output but does lead to increased loss of calcium from the body. However, dietary protein exerts a greater influence than does physical activity. Circulating blood volume decreases somewhat if dietary protein is withheld and significantly if physical activity is also markedly restricted. Future experiments will be concerned with determining man's maximal protein tolerance and minimal carbohydrate requirement and with further exploration of the protein-calcium relationships.

Bioregenerative Life-Support Systems. With the extension of space missions toward the planets, the maintenance of an adequate atmosphere solely from stored gases will become increasingly difficult and perhaps impossible. Studies on the electrolysis-Hydrogenomonas system continue at several different laboratories. Work on extracellular products of Hydrogenomonas eutropha indicates that the amphoteric and extracellular products of this organism enhance its growth, while a cell-free medium depresses growth. Of the many carbohydrate products in the spent medium, fructose, gluconic acid, and 2-keto-D-gluconic acid are used by H. eutropha. To date, no toxic organic compounds have been generated in recycled batch cultures.

The optimal conditions have been established for growth in batch cultures of Hydrogenomonas. To assess the utility of human wastes as part of the growth medium for hydrogen-fixing organisms, it has been shown that diluted human urine, especially its inorganic components, will support the growth of this organism, provided there is no bacterial contamination such as Staphylococci indigenous to the urine.

During 1966, studies continued at RIAS on the coupling of energy-yielding and energy-consuming systems. In addition, an automatic unit for continuous cultivation of hydrogen bacteria was placed in operation and some progress was made in establishing parameters that allow high production rates under steady-state conditions. To evaluate parameters affecting the overall conversion efficiency, cells were cultivated in a turbidostatically controlled, continuous culture unit of 4-liter capacity. The main objective of this study by Medici and Bongers was to define environmental parameters that will produce a maximum cell yield per unit volume of suspension for a minimum of energy input. The preliminary investigations have mainly been concerned with establishing steady-state conditions with regard to nitrogen and phosphate supply. Results obtained indicate that nitrogen must be supplied as an ammonium-urea mixture of 1:2 in order to keep pH constant at a minimum of phosphate buffer concentration. Under the best conditions for the operation of the turbidostat, a rate of growth on the order $K = 0.20 \text{ hr}^{-1}$ and a specific rate of CO_2 fixation of 1 liter/hr (per liter of suspension) were observed. These reproduction rates are about half the best values observed earlier with batch cultures, while efficiencies of energy conversion were about equal.

3. EXOBIOLOGY

Life-Detection Methods

Filter-Wedge Spectrometer. A filter-wedge spectrometer developed by Pimentel and associates at Berkeley has been chosen as one of the scientific experiments to be carried on a Mariner flyby of Mars in 1969. The primary purpose of the infrared experiment on this flyby is the acquisition of data relevant to the possible presence of life, both current and past, on Mars. The chemical considerations of importance in supplying the answers to this problem are the presence of an oxidizing or reducing atmosphere, the presence of polyatomic molecules that suggest biochemical processes, the presence of polyatomic molecules that affect the ambient surface temperature or limit the uv light flux at the surface, and the compositional variations of atmospheric constituents relative to geographical locale. Data relevant to these questions could come from ir spectral studies in the frequency range 2.5 to 15.4 μ . A filter-wedge spectrometer light enough to be carried on a flyby and yet sensitive enough to detect minute amounts of polyatomic molecules in the Martian atmosphere has been developed during the past year and is now operating. This instrument will gather light, both reflected and emitted, from the Martian surface with a Cassegrain-mirror system and will record spectra in the 2.5-to-15.4 μ region once every 10 sec during the encounter sequence. Spectra will be obtained on both the light side and the dark side of Mars. Two separate semiconductor detectors in two different channels are used to maximize the signal-to-noise ratio over this spectral region. Both of the detectors are cooled, one by radiation to deep space and the other by a Joule-Thomson cryostat. The use of this two-channel optical arrangement with two different detectors and advances in filter-wedge construction during the past year have resulted in an instrument with very favorable signal-to-noise levels at 1% resolution throughout the spectral region, in spite of the extremely low energy level that is to be expected during encounter. An earlier version of the filter-wedge spectrometer, designed for telescope use, has also been improved during the past year. It has been used with the Lick Observatory 120-in. telescope to study Jupiter and other planets in the 8-to-14 μ atmospheric window.

Gas Chromatograph Mass Spectrometer. A small combination gas-chromatograph mass-spectrometer instrument is under construction at the McDonnell Company for detecting organic compounds on planetary surfaces. Since most of the biologically important materials do not exist in vapor form under normal conditions, techniques capable of obtaining reproducible pyrograms from organic compounds have been investigated. The identity and concentration of products produced by pyrolysis of amino acids, soil samples, cyclohexane, and cyclohexene have been determined as functions of pyrolysis temperature and carrier-gas flow rate. When pure materials are pyrolyzed, the product distribution is of such a nature as to make parent identification relatively easy. The pyrolysis of cyclohexane at 725°C produced 10 hydrocarbon products, for example, while cyclohexene produced 24. In both cases the primary products were methane, butenes, butadiene, cyclic pentenes and hexenes, and benzene.

Microbial Metabolism. In studies on life detection methods for planetary exploration, Levin at Hazelton Laboratories in Falls Church, Virginia, using an advanced orthophosphate-uptake method, based on the classical life-detection experiment that seeks the metabolic

involvement of phosphorus, reports sensitivities of detection of the order of several hundred bacteria per ml in less than 5 hr. The instrument is known as an automated microbial metabolism laboratory. Levin has also developed an instrument for microorganism detection through adenosinetriphosphate bioluminescent assay intended for mounting in small rockets. The instrument would make determinations of the microbial population in the Earth's upper atmosphere by analysis of particulates collected in flight. It should be capable of executing four analyses in real time during the flight. The now miniaturized instrument contains novel metering and pumping systems.

Isotopic Oxygen Exchange. Refinements have been made during 1966 in a technique developed by RIAS for detecting and studying life on other planets. The principal underlying this approach is that living organisms, even those that are quite unlike terrestrial organisms, will contain enzymes having an ability to catalyze the exchange of labeled oxygen from inorganic oxyanions to water. Increased sensitivity and accuracy of measurements have been obtained by using a double-collector mass spectrometer, in which the isotope ratio of a standard water sample is compared repeatedly with that of a water sample recovered after incubation of soil and labeled anion. The two samples are electrolyzed and the evolved oxygen is passed alternately at atmospheric pressure over the teflon-membrane inlet leak. Only 25 μ l of water needed per analysis where the detectable limit for changes of the mass ratio ($^{32}\text{O}/^{34}\text{O}$) is 0.05. Experiments by Medici during the past year were confined to the exchange between ^{18}O -labeled phosphate and water and to further scrutiny of basic questions concerning the feasibility of the method. Observations of the exchange catalyzed by various organisms, cell-free extracts, and soil samples indicate that the present apparatus can detect about 10^3 organisms of average terrestrial activity within a 24-hr incubation. If soil samples of 0.1 g are used, the detection limit would thus be about 10^4 organisms/g of soil. Presumably, this sensitivity could be enhanced by including growth-stimulating agents during the incubation—such as concentrated soil samples from the alien planet itself. To discriminate between living and non-living systems, experiments were carried out to test whether inorganic or organic non-living materials could carry out an appreciable exchange of oxygen from phosphate to water. No significant interference of such non-living materials has been observed. In fact, simple heat treatment destroyed the exchange capability of soils and cell materials effectively. So far as generality of the method is concerned, all organisms tested have given positive results.

Studies of Terrestrial Substances of Relevance to Exobiology

Analysis of Organic Matter in Ancient Sediments. During the past year, Calvin, Burlingame, and associates at the University of California, Berkeley, using gas chromatography and mass spectrometry as primary tools, have continued investigations into the nature of the hydrocarbon constituents of a representative series of sediments and oils ranging in age from 3 million to 2.7 billion years in age. The Soudan Shale from Minnesota (2.7×10^9 years) has yielded the C_{18} , C_{19} , C_{20} and C_{21} isoprenoid-alkanes. From the Antrim Shale from Michigan (about 265×10^6 years) the C_{16} , C_{18} , C_{19} , C_{20} and C_{21} isoprenoids have been obtained, as well as a C_{16} iso-alkane and the C_{18} and C_{19} cyclohexyl n-alkanes. The San Joaquin Oil (30×10^6 years) and the Abbott Rock Oil (3×10^6 years) were found to contain, respectively, the C_{16} , C_{18} , C_{19} , C_{20} and the C_{18} , C_{19} , C_{20} and C_{21} isoprenoids. In addition, a series of iso-alkanes

(C₁₆-C₁₈), anteiso-alkanes (C₁₆-C₁₈) and n-alkyl-cyclohexanes (C₁₆-C₁₉), as well as a C₂₁ isoprenoid, were obtained from the Nonesuch Seep Oil (1×10^9 years).

It has now been possible to demonstrate the presence in very small amounts of the C₁₇ isoprenoid hydrocarbon in extracts from the Antrim Shale (265×10^6 years) by a combination of glc (gas-liquid chromatograph) co-injection experiments and mass spectrometric analysis. The C₁₇ isoprenoid has thus far not been found in any shale or oil investigated and its presence is of significance in relation to the question of possible precursors of the isoprenoid alkane material found in geological formations. In the course of this work, several isoprenoid type hydrocarbons were synthesized (including 2,6,10-trimethylhexadecane, 2,6,10,13-tetramethylpentadecane, 2,6,10,14-tetramethylheptadecane and 2,6,10-trimethyltetradecane) to serve as reference standards for comparisons with compounds isolated from geological source materials.

To validate the presence of "biological markers" in ancient sediments, thulodite from Canada has been examined by Calvin and co-workers. So far, its hydrocarbon distribution has been found to be no different than in samples characterized as of biological origin. Work is continuing on the characterization of a number of steranes, acids, and bases from the Green River Shale. An analysis of the hydrocarbon constituents of the Moonie Oil from Australia (200 million years in age) has been completed. Several series of hydrocarbons that have been isolated and identified are the C₁₅, C₁₆, C₁₈, C₁₉, C₂₀ and C₂₁ isoprenoids, a C₁₅ iso-alkane, as well as the C₁₈ anteiso-alkane and two members of the cyclohexyl-alkane series (C₁₅ and C₁₆). The analysis of the Moonie Oil derives some significance from the fact that it provides a comparison of the constituents present in an oil from the Australian continent with those present in sediments and oils from other areas.

In August 1966, approximately 50 different samplings of Precambrian and Cambrian shales and slates were taken in Australia, in collaboration with Hoering of the Carnegie Institution Geophysical Laboratory. These samples, many of which are drill cores, range in age from 500 million to 2.3 billion years. They are now being cataloged and cleaned prior to undergoing analysis to determine their hydrocarbon constituents.

Studies of Photosynthetic Halophiles from Owens Lake. Two ways in which the Martian environment differs significantly from Earth are the scarcity of free water and the virtual absence of atmospheric oxygen. This implies that Martian life must either occupy an occasional niche in which free water exists, or must concentrate water from sources in which, by terrestrial standards, it would be tightly bound and unavailable for life. On Mars, energy for synthesis and for the accumulation of water for synthesis would of necessity be derived from an anaerobic process with thermodynamic dependence upon the Sun.

Studies of growth limitations by water or anaerobic photosynthesis under conditions in some way approaching Mars may be accomplished with a number of terrestrial organisms selected from various environments; however, only in rare cases can both be investigated simultaneously. Such investigations are being made by Sweeny and co-workers at Aerojet Space-General Corporation with halophilic, anaerobically photosynthetic bacteria from an halite-thenardite-trona evaporite deposit in the Owens Valley. A purified isolate has been identified as a member of the group of small *Chromatium* species promoting sulfur formation in the growth medium. The optimum water activity for rapid growth of this organism appears to be 0.95. In solutions of NaCl or of sodium carbonates at pH 9.5, growth is a function of water activity; in sodium-sulfate brines the response is also related to a property of the solute. Generation times were 78 and 13 hr in media having water activities of 0.76

and 0.95. Growth has been studied in biphasic systems in which the concentration of more than one solute, water activity, and the composition of the solid phase were predicted by phase rule. Organisms trapped within mirabilite crystals during these experiments survived liquid-nitrogen temperatures and subsequent exposure to vacuum. Initial results of a theoretical study of halophilic growth indicated that, in the saturated solutions used, water does not move osmotically but must be pumped into the cell.

The transition from the log-to-log stages of growth involves the utilization of sulfide with the production of an enlarged sulfur globule followed by a reduction in size to normal-sized rods. That the sulfur globules appear to be less dense than the intact cell suggests the mode of water entry into the cell may involve the transfer through a sulfur cycle. Bacteriochlorophyll, associated with the red-purple pigmentation observed in later stages of growth, does not appear until after the sulfides have vanished, thus suggesting that Chromatium may be initially dependent upon sulfides as an energy source and later upon the ability to synthesize bacteriochlorophyll photosynthetically.

The effect of the medium on growth of the Chromatium in their crystalline environment was also studied. The organisms in an Owens Lake environment, either as the salt cake or from recrystallized brine, are present in vacuoles in the crystal having dimensions similar to the organisms. The environment the organism experiences appears to be that of the salt cake; it is appears that the environment that the organism experiences is that of the salt cake; it is not clear, however, whether this includes water as a hydrate, or whether free water trapped in crystal defects is the preferred source. Organisms trapped in mirabilite crystals appear to be found in pockets with principal dimensions about 10 times that of the organism. The pockets are typically half-filled with brine and the cells may move about in these pockets.

Unusual resistance to a variety of environments is shown by the Chromatium. Both high (180°C) and low temperatures (-60°C) are withstood, and growth under low pressure (~30 mm Hg) approximating Martian conditions may be greater than at an Earth atmosphere. Light appears necessary for growth. Current effort is directed toward determining the mechanism by which photosynthetic growth is maintained in a water-limiting environment and to defining the physiological parameters that enable the organism to survive extreme conditions of temperature and pressure.

Growth of Organisms Under Simulated Planetary Conditions. At the Institute of Molecular Evolution of the University of Miami, evidence has been collected by Fox and colleagues to demonstrate that synthetic bacteria-sized proteinaceous particles will proliferate under simple conditions that are postulated to exist on planets such as Mars. Rates of hydrolysis of thermal polyanhydro- α -amino acids have been studied to determine if analyses can be completed in a few hours by a lander on Mars. Four hours has been found to be sufficient to obtain the necessary data. Investigations in collaboration with Durrum of Durrum Instruments Corp. on an extraterrestrial sampler for biopolymers have been concerned with paper electrophoresis scanning techniques and the power requirement for hydrolysis.

Amino acids have been sought in lava, volcanic sinter, and volcanic ash as a guide to what may be expected on the Moon or Mars. In bacteria-free samples, approximately 1 to 2 ppm have been found to be present. The amino acids are polymerized. Properties of the proteinoid microspheres have been studied as a prelude to experiments at zero gravity with the plan of using these units as controllable models of cells. Studies of proteolysis and nutritive quality of proteinoids have continued. These materials are of interest for life support and for simple chemical synthesis of food in prolonged sojourns on the Moon, etc. Various

fractions of a thermal copoly (glutamic, glycine, tyrosine) have been shown to have markedly different susceptibilities to chymotrypsin.

Enzyme Activity in Terrestrial Soil in Relation to Exploration of the Martian Surface.

Qualitative and quantitative tests for various enzyme activities in soil are being developed by McLaren and Skujins at Berkeley for an eventual incorporation of the most suitable procedures in Mars probes. In addition, enzyme reactions in environments of limited water availability and at interfaces are studied. A fluorometric technique was developed for the determination of phosphatase activity in soils based on the measurement of β -naphthol released to the soil extract upon hydrolysis of Na- β -naphthylphosphate. A spectrographic analysis of the fluorometric assay demonstrated that the detection of β -naphthol released to the soil extract was not affected by either the unhydrolyzed substrate or the soil extract in the soils tested.

Several factors correlating soil enzyme activity and microbial numbers were also examined. No correlation was found between the seasonal variation in microbial numbers and phosphatase activity. Increases in both phosphatase activity and microbial numbers, however, were found following inoculation of sterile, irradiated soil with a trace of native soil. The lower the moisture content of the soil at the time of irradiation, the less was the inactivation of phosphatase activity observed in soil irradiated with an electron beam at a given dose. It is evident that the phosphatase activity in soils reflects more than just the metabolic activities of live microbes and includes a relatively stable, extra cellular component of enzyme in soil matrix. An attempt was made to locate the microsites of soil phosphatase activity with electron-microscopic methods.

McLaren and Skujins have also developed a simplified method and instrumentation to measure the rate of $^{14}\text{CO}_2$ release in soil from ^{14}C -labeled substrates, especially from ^{14}C -urea. Geologically preserved ^{14}C -dated soils, soils stored over 70 years, and soils from adverse climatic conditions were examined for urease activity. Relatively high activity values were obtained from 8715- and 9550-year-old permafrost-peat samples, whereas some limited activity was evident in a 32,000-year-old buried soil sample. Urease activity in the 70-year-old "Hilgard Soils" reflected the sampling locale, sampling depth, and previous biological history of the soils; the activity could be correlated with the organic matter content but not necessarily with the numbers of surviving organisms. The experimental arrangement permitted a separation of the apparent "intrinsic" urease activity from that caused by bacterial proliferation.

The study of the hydrolysis of urea by urease at a limited water availability was continued. It was demonstrated that dry urea intimately mixed with urease and placed in an atmosphere of 100% relative humidity was hydrolyzed to completion, whereas below 65% relative humidity there was no reaction. Tests on the stability of urea at elevated temperatures showed that after sterilization at 140°C for 35 hr, about 80% of urea present remained available as a substrate for urease. The temperature and the exposure time at which the stability of urea was examined were above the current NASA requirements for spacecraft sterilization.

A study of surface effects in the hydrolysis of insoluble chitin by adsorbed chitinase and lysozyme is being continued in order to investigate some of the factors influencing enzymatic reactions at interfaces.

4. PLANETARY QUARANTINE AND SPACECRAFT DECONTAMINATION

In support of one of the primary missions of planetary exploration—the search for extra-terrestrial life, precursors or remnants—a planetary quarantine program was established within NASA in 1963 with authority to prescribe and implement decontamination, sterilization, and quarantine procedures. In accord with recommendations of the Space Science Board of the U.S. National Academy of Sciences and the Committee on Space Research of the International Council of Scientific Unions, these efforts are directed toward the control of biological contamination transmitted between the Earth, Moon, and planets of biological interest. All lunar landing or orbiting spacecraft are decontaminated to the greatest degree possible, consistent with the state of the art, i.e., the levels of microbial surface contamination are kept to a minimum short of actual heat sterilization. An inventory of viable particulate contamination is maintained for each spacecraft intended to travel beyond the gravitational influence of the Earth; those proposed for planetary encounter must be sterilized to a degree that insures that no viable organism survives with a certainty of 0.999.

Spacecraft Sterilization and Contamination-Control Technology. Research conducted in the Experimental Assembly Sterile Laboratory at JPL has developed practices and techniques that reduce microbial contamination by several decades during the spacecraft-assembly and check-out process. Most of this reduction is achieved through the use of laminar airflow systems and careful personnel-garmenting practices. These basic results have been utilized in the design and construction of a Sterile Assembly Development Laboratory where a prototype assembly and sterilization system will be developed, using a large-sized mock-up of a planetary lander, to provide the data required to formulate final procedures for planetary missions.

Considerable progress has been made in the determination of thermal-death curves for various spores subjected to dry heat at temperatures between 105°C and 160°C. Studies of recovery of organisms in solid plastic materials have resulted in lower temperature-time values for sterilization of interior of spacecraft components than those based on the early studies with soils. Further work is in progress on the thermal requirements for killing organisms on mated surfaces or encapsulated in potting compounds such as epoxy and conformal coatings.

Investigation of the mathematical parameters associated with dry-heat sterilization indicates that a microbial burden of 10^5 organisms is achievable prior to sterilization using available technology and that a heat cycle of 24.5 hr at 125°C will provide the desired confidence level for achieving the sterility of the biobarrier and capsule prior to launch. Currently, hardware development is proceeding on the basis of this cycle as the qualifying test.

The McDonnell microbiology group has conceived a double-walled glove box for sterile assembly of heat-labile components. Sterility of the internal environment is maintained by passage of components through peracetic-acid baths and exposure to ethylene oxide. The unique feature of the system is a physical particulate-monitoring system. Sterile fluorescent particles, of the same size as bacterial spores, are aerosolized into the chamber between the inner and outer walls. Glove-box penetrations permitting leaks into the external room or into the sterile assembly chambers will be immediately detected by electronic monitoring equipment. This technique obviates the problems in culture-time delays related to utilizing viable organisms as monitoring media. The validity and reliability of the approach is now established;

the next phase will consist of actual assembly of components in the glove box, with microbiological demonstration of sterility.

Some biological fluids that will probably be used in interplanetary spacecraft experiments are heat labile and therefore will have to be sterilized separately and added to the vehicle after it is heat treated. In an effort to determine whether filtration could be used to produce a filtrate having a probability of sterility equivalent to that required by NASA, tests were run at Ft. Detrick by the Army on diatomaceous earth, fritted glass, asbestos pad and membrane filters. The results revealed that to be assured of a high probability of sterility the filtration system should be pretested with highly contaminated biological fluid of the type needed for the experiment and then it would be advisable to filter twice the fluid actually used.

Tests were run to determine whether it is more difficult to kill microorganisms located between two tightly fitted solid surfaces (mated surfaces), than organisms on external surfaces. Surprisingly enough, organisms in one location were killed as readily as those in the other when subjected to either heat or ethylene oxide. The mated surfaces were bolted or clamped together in these tests but were not necessarily hermetically sealed. This is in contrast with the increased resistance previously noted with microorganisms actually encased in solids, such as plastics, or embedded in soil.

Studies were initiated to determine the effectiveness of an ethylene oxide-methyl bromide mixture as compared with ethylene oxide alone for gaseous decontamination. Preliminary tests indicate there is no synergistic effect of the methyl bromide on the effectiveness of ethylene oxide to kill organisms on surfaces. Studies are continuing to determine if the penetrability of the mixture is any better than that of ethylene oxide alone.

Initial studies reveal that it is more difficult to kill microorganisms included in crystals than to kill organisms on surfaces. Further studies are being conducted to obtain complete death-rate curves.

Celestial Mechanics and Trajectory Studies

Investigations in celestial mechanics and trajectories are numerous. Some of the studies derive their interest from novel mathematical or computational developments, others from the physical data they yield, especially data on the distribution of mass in the solid Earth. This section makes no attempt to be complete; see Bibliography, Section 1, for references to other works.

1. CELESTIAL MECHANICS

The n-Body Problem with Applications. The binary collision in the n-body problem and in certain perturbed two-body problems has been studied at NASA's Marshall Space Flight Center. Based on a generalized definition of a binary collision, a rigorous proof has been given that Sundman's integral converges as the instant of a collision is approached, i.e., that Sundman's variable exists. All variables are allowed to be complex, and the path on which the time t approaches the instant of collision obeys certain restrictions; it need not be a straight line, however. The Lagrange-Jacobi equation is the key to the proof of the existence of Sundman's variable, which in turn is basic for all regularization procedures.

The existence of Sundman's variable has also been demonstrated in the perturbed two-body problem, if some restrictions are satisfied by the perturbing forces. It is sufficient that they possess a potential remaining bounded together with its partial with respect to time; the reduced three-body problem is an example of this type. The question of the existence of Sundman's variable has been overlooked in the literature on this problem.

Also at Marshall Space Flight Center, new periodic solutions have been discovered for the plane three-body problem corresponding to elliptic motion in the lunar theory. It has been established that the problem of three bodies in a plane, with arbitrarily preassigned (positive) masses, admits denumerably many two-parameter families of solutions which represent periodic motions. This result includes the existence of denumerably many one-parameter families of periodic solutions of elliptic type for the restricted three-body problem with arbitrary mass ratio and for Hills' lunar problem. Applications to the astronomical lunar

theory and the astronomical restricted four-body problem by adding a space vehicle of negligible mass have been considered.

In addition, new one-step integration methods having high-order accuracy have been developed at Marshall Space Flight Center and applied to some problems in celestial mechanics. These new methods are essentially a combination of power-series expansions and Runge-Kutta methods. When applicable, these new formulas have the following definite advantages, compared with standard Runge-Kutta formulas: they yield any order of accuracy one might desire; they require only very few evaluations of the differential equations; they include a very simple and economical method of step-size control. Applications have been made to the equations of motion of the restricted three-body problem and the restricted four-body problem.

Research in celestial mechanics and trajectory studies at the Jet Propulsion Laboratory has been concerned with many dynamical problems that arise in celestial mechanics, in which changes of independent variable are performed. In conservative systems, general rules for performing this operation have been given, but nonconservative systems have been only slightly studied and probably no general theory exists. It is the purpose of this research to show that, even for nonconservative systems, a general rule can be found for the transformation of the Lagrangian when a new independent variable is chosen. Applications to the two-body problem and to the elliptic restricted three-body problem have been worked out.

Development at JPL of the manner in which the six orbital elements of the classical two-body problem vary with coordinate time according to the theory of general relativity has led to a relativistic generalization of Kepler's equation. The averaging method of Krylov-Bogoliubov was used in obtaining the generalization of Kepler's equation by means of the Schwarzschild line element and two first integrals which arise from this line element.

A study conducted by the Douglas Aircraft Company Physical Sciences Department applies new perturbation techniques, particularly the method of matched asymptotic expansions and the two-variable expansion procedure, as developed at the California Institute of Technology, to various problems of celestial mechanics. The solution of Earth-to-Moon trajectories is being extended to a realistic model of the Earth-Moon system, considering the ellipticity of the Moon's orbit as well as the most important terms of the perturbations by the Sun. This work is nearly completed. Analytic solutions were derived for the motion of a space vehicle propelled by a low thrust. Solutions valid before escape were obtained for the case of elliptical initial orbits with arbitrary eccentricity and for the case of decreasing mass of the vehicle. The singularity in the expression for the radius and velocity vectors, which occurs in the escape problem, was removed in the case of a circular initial orbit. The two-variable expansion procedure, which has been largely used at Douglas to obtain analytic solutions to various perturbation problems, was developed further and shown to be equivalent to the classical von Zeipel's method.

An extensive study has been made by Bray and Goudas at Boeing Scientific Research Laboratories of various types of three-dimensional periodic motions in the restricted problem of three bodies, with particular emphasis on simply and doubly symmetric orbits. For each family of orbits there exists a critical inclination, in the sense that orbits of the family with larger mean inclination than this are unstable. An analytical treatment of the secular perturbations of the elements of satellite orbits of the Earth or Moon caused by external bodies is given in terms of first powers of certain parameters, which specify the magnitude of the disturbing force. The expressions obtained are concise and suitable for even highly eccentric and inclined orbits.

Under certain simplifications, the equations describing the long-term behavior of a satellite

disturbed by a third body reduce to a third-order (nonlinear) system that can be integrated completely. Elliptic integrals are required for the time dependence but the phase trajectories can be represented entirely by elementary functions. A complete description of the behavior of solutions to these equations has been worked out by mathematicians at JPL.

Research by Lanzano at North American Aviation has yielded certain contributions to the topic of periodic orbits for the circular restricted three-body problem: (1) Intrinsic representation of a generic orbit, whereby the curvature of the orbit is expressed in terms of the velocity and the angle between orbit and zero-velocity curve; (2) Application of the previous representation to a periodic orbit, i.e., the period of the orbit is given as a double integral of a function of velocity, extended to the area bounded by the periodic orbit; and (3) Study of periodic, isoenergetic, infinitesimal displacements by means of periodic solutions to a Mathieu equation, and expressed as a trigonometric series in time, with coefficients as power series in a parameter related to the initial conditions. Two other contributions pertain to the elliptic restricted problem, namely, power series in the eccentricity of the primaries and series solution for a generic orbit about a Lagrangian point.

Deprit and co-workers at Boeing are exploring the feasibility of mooring a communications satellite at the equilibrium centers of libration L_4 and L_5 in the Earth-Moon system from the standpoint of celestial mechanics. Leontovich's theorem has been refined to show that the equilibrium configurations L_4 and L_5 are stable in the sense of Kolmogorov and Arnold for all admissible ratios except three critical values. The Hamiltonian function at these equilibrium configurations has been normalized, first for any value of the mass ratio (but only up to order 3, by long-hand methods) and then for a given value of the mass ratio (but up to order 13 by extensive symbolic manipulations on a computer). The programs have been applied to the Earth-Moon and the Sun-Jupiter systems. In the case where the equilibrium center L_4 is stable in the sense of Kolmogorov, the families of periodic orbits emanating from it have been extended, first analytically by implementing Poincaré's method of continuation on a computer up to order 15, then numerically by a predictor-corrector procedure based on the numerical integration of Hill's equation for normal isoenergetic variations and its extension to nonisoenergetic displacements. This task has been completed in the Earth-Moon case, and it is nearing completion in the Sun-Jupiter case. A similar task has been completed for the critical mass ratio of order one (Routh's value) where several double families of periodic orbits have been found to bridge the two branches emanating from L_4 . Beyond Routh's singular mass ratio where there is instability to the first order, there still have been found periodic orbits around L_4 whose characteristic exponents are, surprisingly enough, of the stable type.

Cohen and Hubbard of the Naval Weapons Laboratory, Dahlgren, Virginia, fit an improved orbit to observations of Pluto made during the past 50 years. The computations were performed by numerical integration, taking direct account of the effects of the other outer planets. Keplerian differentials, used in initial computations, failed to yield minimum residuals. The semi-major axis of the final orbit was found to be 0.075 AU smaller than that in A.P. Vol XII with a standard deviation of 0.0006 AU.

The differential equations for the motion of the Earth-Moon barycenter, considering the Earth and Moon as separate bodies, have been worked out at JPL. The ephemerides of the Earth-Moon barycenter, Venus, Mars, and Mercury, constructed with these differential equations were compared with the ephemerides of the same planets constructed with differential equations in which the Earth and Moon were considered as a point mass located at the barycenter of the Earth-Moon system. Position residuals and angle residuals between the two systems were plotted on graphs.

Experimental Determination of Astronomical Constants. At Arecibo Ionospheric Observatory, the range (propagation time) to both Venus and Mercury are measured to a precision of from 10 to 100 μ sec, depending on the available signal-to-noise ratio, several times each week when the planets are in the observing declination zone of the Arecibo planetary radar system (essentially the summer six months of each year). A catalog of these observations from 1964 is being compiled. Since these observations are several orders of magnitude more precise than optical observations of these planets, they serve as a powerful source for the computation of precise ephemerides for the Earth, Venus, and Mercury, which are vital for deep-space guidance and navigation purposes. Furthermore, it is clear that the observations, when available over sufficiently long periods, will serve for definitive testing of various gravitational theories, e.g., general relativity, for the study of the interplanetary and coronal plasmas, and for the determination of the system of astronomical constants. Currently, the analytical work is being carried out at the Center in cooperation with groups at MIT's Lincoln Laboratory and JPL.

Observations are under way at the Naval Research Laboratory that are expected to lead to an independent determination of the astronomical unit by observing the absorption lines of neutral hydrogen over a period of one to two years. The receiver utilizes frequency switching and 50 contiguous crystal filters each having a 4-kHz bandwidth. The local oscillator is derived from a cesium-beam frequency standard permitting long-term frequency stability of the order of one part in 10^8 . The cesium standard is periodically checked against the Laboratory's hydrogen maser. Modifications will be undertaken to use the OH lines as well as the hydrogen lines.

2. INTERPLANETARY TRAJECTORY ANALYSIS, DESIGN, AND OPTIMIZATION

At JPL the general characteristics of ballistic interplanetary trajectories have been discussed and detailed equations have been developed for the analytical model. Extensive data were worked out in graphical form for trajectories to Mercury (launch dates: 1968-1973). These graphs include curves of vis viva geocentric energy versus launch date for minimum-energy trajectories and curves of about 20 different trajectory parameters versus launch date for various vis viva geocentric energies. The trajectories were computed on the IBM 7090 digital computer by numerical evaluation of the analytical model, after which specific parameters of interest were automatically plotted, carefully checked, and analysed. Procedures were outlined for use of these data by the trajectory engineer in designing and analysing interplanetary trajectories.

A comprehensive analysis of trajectories and propulsion-system requirements for exploration of the solar system was conducted by United Aircraft Research Laboratories for the NASA Ames Research Center. In this study, high-thrust and low-thrust propulsion systems were examined for missions to all classes of objective bodies in the solar system. Work is continuing to develop user-oriented computer programs for solving selected problems of trajectories and system optimization peculiar to low-acceleration, constant-thrust interplanetary vehicles. Mars-stopover missions were also analysed for different propulsion systems and for various planetary-capture schemes, with trajectories optimized for minimum energy. Utilizing various alternative mission-mode studies, mass requirements can be significantly reduced and can, in some cases, be coupled with operational advantages relating to increased mission success.

Further United Aircraft research included study of the general problem of retrieval of unmanned planetary probes. An analytical-graphical method was developed to determine the communication distance of a returning flyby probe and an analysis was made of the return peri-passage distance as an indication of the probability of favorable probe return and subsequent transmission of data. In a separate study, the effect of a gravity field on the required characteristic velocity for capture or departure was calculated as a function of thrust-to-weight ratio for propulsion systems ranging from pure low-thrust systems to pure high-thrust systems in which impulsive thrust approximations are normally considered adequate.

Mathematicians at JPL, working out the trajectory design for a spacecraft that would return to the vicinity of the Earth after the Mars encounter, have shown that it is possible to fly a purely ballistic roundtrip mission with relatively short flight time. Many kinds of encounter geometries at Mars are also possible, some of which would be suitable for television pictures and other scientific experiments. If it is necessary to carry out a velocity-correction maneuver at Mars because of the difference in asymptote of approach and departure, the roundtrip trajectory is called "impulsive." By using a velocity increment, it is often possible to improve the trajectory characteristics or mission payload. JPL has also developed a method and associated computer programs useful for analysing Earth-Mars-Earth trajectories based on the patched conic model. The return probe could transmit up to 1000 times more data during the Earth-encounter phase than can a non-return flyby such as Mariner 4. (Owing to communication distances and small transmitter powers, a Mars flyby is severely limited in the quantity of data it can return. A Mars orbiter could obtain a great deal more data and has been the topic of much investigation.) It has been concluded that, compared with the 1969, 1973, and 1975 Mars opportunities, the 1971 Earth-to-Mars launch period is most advantageous for Earth-return missions.

United Aircraft has conceived and evaluated the potential of a unique Flyby Landing-Excursion Mode (FLEM) which offers significantly reduced orbital mass requirements and possible reduction in the trip times associated with manned interplanetary-stopover missions.

Advantages with respect to propulsive energy by using three-impulse rather than the more conventional two-impulse interplanetary-rendezvous trajectories are also being evaluated at United Aircraft. Results indicate sufficient potential to the multiple-impulse mode that possible mass advantages are being evaluated and optimized trajectory analyses being made. In addition, low-thrust interplanetary trajectories were computed which emphasize compatibility with the characteristics of nuclear-electric powerplants. Current trajectory work is aimed at the compilation of a handbook of low-acceleration trajectories and information suitable for preliminary analyses of missions and systems.

The problem of minimizing the initial impulse required for the transfer between two terminal points in space under an arbitrarily prescribed initial velocity vector was investigated analytically by F. T. Sun at the University of Michigan. The chordal and radial components of the in-plane velocity were employed. In terms of these velocity coordinates, Stark's optimum quartic equation was reformulated and critically examined for the number and nature of its real solutions. Analytical criteria for the unrealistic optimum were derived and the selection of a realistic transfer trajectory under various conditions of the initial velocity vector were considered and summarized in some simple rules. Various regions in the hodograph plane concerning the nature of the optimum-transfer trajectories were established and the effects of the initial velocity vector on such a trajectory were analysed. An optimization chart was developed and the construction of two versions of the optimum transfer hodograph was introduced. Several limiting cases, including the vertical transfer, the 180° transfer, and the

transfer to infinity were investigated and the particular case of departure from a circular orbit was also reviewed. The analysis was basically two-dimensional with a brief consideration of the three-dimensional effects.

3. EARTH ORBITAL ANALYSIS, DESIGN, AND OPTIMIZATION

At the University of Colorado, Busemann has worked out the advantages of approaching orbital change problems using the configuration space introduced by him in the 1965 Prandtl Lecture in Vienna, combined with the geometrical properties inherent to Keplerian orbits. The visualization thus made possible, together with the fact that in this configuration orbital problems remain problems of conics, provide the investigator with an advantageous head start. Many results that require tedious calculation if attacked in more common ways are immediately evident. The problem used to illustrate the technique is the general problem of descent from an elliptical orbit. Motion is restricted to a plane. The deorbit maneuver was considered to be subjected to various constraints and the resulting geometrical constraints were developed.

It is well known that the solution of the equations of motion of a particle in the gravitational field of a central body can be expressed in terms of Weierstrass functions or Jacobi functions. The use of this solution for practical numerical calculations supposes that the necessary algorithms or subroutines to compute these functions are available. Besides the existing solutions, the solution is developed at JPL in simple recurrent Taylor series that are easy to manipulate numerically even on a small computer, and with a high degree of accuracy. The polar angle φ is the independent variable and the radius r and time t are taken as dependent variables. The purpose of this research was to obtain, for all the coefficients of a Taylor infinite series, simple expressions that are functions of the initial conditions only.

Trajectories of satellites under the influence of Earth oblateness and air drag have been derived by the asymptotic method in nonlinear mechanics by scientists at Grumman Aircraft Engineering Corporation. Closed-form solutions for the improved first-order approximation are obtained, based on the assumptions: (1) that the second harmonic (J_2) is the dominant oblateness factor of the Earth; (2) that one has a nonrotating, spherically symmetric atmosphere and an exponential distribution of atmospheric density; and (3) that the original elliptical orbits are of small eccentricity. After finding the osculating orbital elements of the resulting trajectories, the behavior of osculating orbits at various inclinations is elucidated.

An explicit guidance law of orbital rendezvous, based on a solution in terms of perturbations from two-impulse transfer, has been derived by Zee at Grumman for a satellite and a target orbiting closely in two nearly circular orbits with small inclinations. By introducing a fictitious satellite, which has a circular orbit and is close to the satellite and the target during the entire rendezvous period, and which constitutes the center of the usual coordinate system of rendezvous problems, the linearized equations of motion are solved for fixed-orientation thrust-powered flight and free flight. A determination of thrust orientation and thrust duration for the two thrusting periods of the rendezvous scheme constitutes the required guidance law.

Laboratory Astrophysics and Special Techniques

The term "laboratory astrophysics" is intended to suggest the experimental measurement and theoretical calculation of fundamental atomic and molecular quantities needed to interpret measurements made by space experiments of extraterrestrial objects, the interplanetary and circumterrestrial medium, and the upper atmosphere; for instance: spectra of atoms and molecules (wavelengths and intensities, analysis of energy levels continua) especially at high temperature and low density, or in wavelength regions accessible only from space; transition probabilities or radiative lifetimes; and collision cross sections or rate coefficients for many atomic or molecular reactions. The final section in this chapter includes a few notes on instruments. (Where the laboratory work is closely associated with a particular aspect of space research, e.g., the lunar surface, it may be discussed in that chapter.)

1. SPECTRA AND ASSOCIATED QUANTITIES

In this section are listed the laboratory researches (experimental or theoretical) in which the emphasis is on the measurement of wavelengths and line or continuum intensity, the analysis of energy levels, the calculation of transition probabilities (or equivalently, oscillator strengths or lifetimes), and so on.

Many programs at the National Bureau of Standards seek to provide fundamental atomic and molecular data over wide ranges and with high accuracy, necessary for the interpretation of measurement of phenomena obtained from space experiments, such as solar radiation, atmospheric reactions, and exotic rocket-propulsion systems. Examples are: atomic energy-levels, transition probabilities for atomic energy-states, and energy release or absorption when atoms and molecules interact with radiation. NBS has developed a method, using lasers, to study two-photon processes that play a role in energy-transfer processes in the upper atmosphere. The method has been tried on cesium vapor and negative iodine ions, and two-photon absorption has been observed.

Since negative ions of oxygen and hydrogen also play an important role in atmospheric and astrophysical problems because of their capacity for absorbing light, a technique for the study

of light absorption by negative ions has been developed which maintains temperatures and pressures characteristic of relevant atmospheric conditions.

Analyses of the atomic spectra, with emphasis on the rare-earth elements and ions (Er I, Yb I-IV), and the energy levels determined from the spectra are becoming increasingly important in interpreting the data received from the Orbiting Observatory projects. A number of atomic spectra (of Si I & II, Fe I, C I, N I, Cu II, and Ge II) have been newly observed in the vacuum ultraviolet, both for analysis and to obtain more accurate wavelength standards in the region 500 to 2000 Å. These should help to resolve the backlog of unidentified spectral lines already taken from rocket spectrographs.

The first of a proposed series of critical compilations of data on the structure and spectra of diatomic molecules was published as "The Band Spectrum of Carbon Monoxide" (NBS Monograph, NSRDS-NBS-5, July 8, 1966). These surveys will provide the "best values" available for scientists working on high-temperature reactions, the Earth's upper atmosphere, the Sun, and other celestial bodies.

At the Naval Research Laboratory Rocket Astronomy Branch, spectra of highly ionized species in atomic nitrogen and oxygen have been newly photographed at high resolution (± 0.04 Å) below 400 Å. A second example of asymmetrical, autoionized emission lines has been observed beyond the first ionization limit in N III. Some very broad autoionized lines with half-widths ≈ 3000 cm⁻¹, which indicates extremely short lifetimes for the emitting levels, have also been observed in this short-wavelength region.

In a joint project between NRL, the National Bureau of Standards, and the National Research Council of Canada the D¹Δ and I¹Σ⁻ states of CO have been characterized and studied in detail from high-resolution vacuum-absorption spectra. The first example of an electronic quadrupole transition in a heteronuclear diatomic molecule has been observed for the electric dipole allowed A¹π - X³Σ⁺ transition in CO. High-resolution spectra of the ¹³C¹⁸O molecule have been photographed to establish uniquely the vibrational numbering of all states in carbon monoxide between 6 and 12 eV. Several previously unobserved bands have been identified in the spectra of HCl and DCl which have been photographed at high resolution in the wavelength region 1350 to 1180 Å.

New photoelectric measurements of the auroral excited transitions, C³π_u - B³π_g and B³π_g - A³Σ_u⁺, in molecular nitrogen have been obtained by NRL in association with the University of Maryland and Johns Hopkins University. These observations combined with the recent molecular data derived from high-resolution spectroscopic studies of molecular nitrogen in this laboratory should yield more exact information about excitation processes in the aurora.

At the Aerospace Corporation, the O₂ absorption windows in the vicinity of 1100 to 1200 Å have been studied by Cook and Ching who employed a continuum light source and a 0.3 Å band-pass monochromator. Windows observed were at 1215.7, 1188.0, 1166.8, 1156.0, 1144.0, 1127.0, 1109.0, 1094.9, 1077.0, and 1068.7 Å with absorption coefficients of 0.26, 0.115, 0.241, 0.367, 0.330, 0.421, 0.279, 1.29, 2.09, and 1.70 cm⁻¹, respectively. Penetration depths for 1/e absorption of solar radiation in the atmosphere were calculated using the O₂ concentrations listed in the COSPAR International Reference Atmosphere of 1965, and found to be 84.6, 86.5, 83.8, 75.5, 78.0, 76.5, 77.0, 74.5, 70.0, and 75.0 km, respectively, for these windows.

At Boeing Scientific Research Laboratories, laboratory measurements are being made of the energies of electrons and ions released in the photoionization of several gases, particularly nitrogen, oxygen, and argon. The wavelength range extends down to 358 Å. The objective is to identify thresholds for various photoionization processes, to obtain the relative

probabilities (including Franck-Condon factors) of transitions from the ground state of a neutral molecule to various states of the molecular ion, and to obtain shapes of potential curves of molecular ions above ionic dissociation thresholds.

Air Force Cambridge Research Laboratory has a threefold laboratory program for the determination of absolute transition probabilities (*f*-values) or radiative lifetimes of astrophysical interest needed for use with the Air Force 60-in. telescope that is currently being installed at the AURA-operated Cerro Tololo Inter-American Observatory in Chile.

The AFCRL optical shock tube is being used to obtain complete gas diagnostics on every shot including the routine measurement of gas kinetic temperature by a new ultrasonic method. Comparison of simultaneous ultrasonic and line-reversal measurements behind the reflected shock gives the same temperature within their standard deviations of about 2%. (The ultrasonic method can be refined and has already been used simultaneously over unequal paths to eliminate boundary-layer effects, and has been extended to the determination of the transport properties of gases and the elastic coefficients of hot solids.) Absolute *gf*-values have been obtained for more than 40 Cr I lines in 13 multiplets based on from 5 to 22 independent determinations per line. The preliminary application of these *gf*-values to the chromium abundance in the Sun and stars indicates that the systematic increase in *gf*-values with excitation potential found by other workers may have been spurious. Simultaneous photographic recording and multichannel photoelectric measurements are used. Both static and dynamic (100 kHz) mass spectrometers and an absorption spectrophotometer are being installed. Future plans include gas densitometry, either by an electron-beam gas densitometer or by a custom-built Mach-Zehnder interferometer with a giant-pulse laser source. The Mach-Zehnder is also available for the "hook" method for absolute *f*-values. A photographic $H\beta$ line-profile electron-density method can also be used simultaneously with the multichannel photoelectric line intensities.

Over 100 radiative lifetimes for numerous ionization states of C, N, O, and Ne have been determined (and many reported in 1966 for N II-V and O II-VI) with Bashkin's foil-excitation method at the AFCRL Van de Graaff accelerator. Complete pulse-counting equipment is being acquired and a McPherson Czerny-Turner half-meter vacuum spectrograph is being adapted to permit measurements from 1050 Å to the near-infrared.

Among AFCRL's plans are: (1) a stronger magnet that will permit measurement of ions of the iron group to give a completely independent check on the shock-tube method; (2) a superconducting magnet to separate the different ionic species of a given isotope; (3) a multi-exponential computer-analysis program to attack the problem of cascading into the upper levels; (4) direct measurements in diverse spectral regions of the lifetimes of transitions that cascade into the upper levels of transitions of interest; and (5) relative *f*-values of all the transitions having a common upper state, in order to convert the lifetimes (and all the relative *f*-values) into absolute *f*-values.

The third program at AFCRL is designed to measure radiative lifetimes of neutral and ionic states of atoms and molecules directly in nanoseconds. The atoms and molecules will be excited by a low-energy electron beam with a sharp upper cutoff in both time and energy. The measuring equipment is on hand and the electron-beam and optical setup is being completed.

2. REACTION RATES AND ASSOCIATED PARAMETERS

This section reports laboratory researches in which the emphasis is on rates of reaction and related cross sections, e.g., association-dissociation, ionization-recombination, collisional excitation-deexcitation, charge transfer, photodetachment, and combinations of these processes.

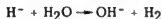
At the Joint Institute for Laboratory Astrophysics of NBS and the University of Colorado, a very extensive program of study in atomic and molecular physics, radiative transfer, aerodynamics, and astrophysics continues, in which the following examples are relevant to space research: (1) Photodetachment rates of O_2^- and O_3^- were measured, as well as the rate for the process producing O_3^- . A measurement of the cross section for the process $H^- + e \rightarrow H + 2e$ was made in a crossed-beam apparatus; this was important not only as the first study of a reaction of this type, but also because there were orders-of-magnitude uncertainty in the theoretical estimates of the cross section. (2) Investigations were made on cross sections for the collisional excitation of highly ionized atoms needed for the interpretation of the far-ultraviolet solar spectrum. Ions studied included Fe XIII, Fe XV, and Fe XVII. Transition probabilities for many lines in Fe XVII were also computed. The new data on Fe XVII explain the rocket-observed intensities of the resonance lines of Fe XVII.

At ITSA's Atmospheric Collision Processes Laboratory, a number of negative ion-neutral reactions of importance in controlling the negative-ion composition and electron density of the D region have been measured by Fehsenfeld and others. These include a number of fast associative detachment reactions including $O_2^- + O \rightarrow O_3 + e$ with a rate constant $2.5 \times 10^{-10} \text{ cm}^3/\text{sec}$ at 300°K . A number of fast charge-transfer reactions have also been measured including $O_2^- + O_3 \rightarrow O_3 + O_2$ with a rate constant of $4 \times 10^{-10} \text{ cm}^3/\text{sec}$. Additionally O_3^- is found to react rapidly with CO_2 in the reaction $O_3^- + CO_2 \rightarrow CO_3 + O_2$, $k = 4 \times 10^{-10} \text{ cm}^3/\text{sec}$. This sharply limits the possible O_3^- concentration in the D region. Reactions of CO_3^- and O_3^- with NO produce the very stable negative ions NO_2^- and NO_3^- which may be terminal D-region negative ions.

The reaction of $O^+ + N_2 \rightarrow NO^+ + N$ has been measured by Schmeltekopf and others as a function of N_2 vibrational temperature from 300 to 5000°K . The rate constant increases about a factor of 30 in this range. This effect has been invoked to account for a decrease in F-region electron density under disturbed ionospheric conditions.

The reaction $H^- + H \rightarrow H_2 + e$ has been found to have a rate constant of $10^{-9} \text{ cm}^3/\text{sec}$. This previously unmeasured reaction is the main loss process for H^- ions in the solar chromosphere and thus is responsible for maintaining local thermodynamic equilibrium between H and H^- in the lower chromosphere.

At AFCL, a fast negative ion charge-transfer reaction, $O^- + NO_2 \rightarrow NO_2^- + O$, was studied and a rate coefficient of $1.2 \times 10^{-9} \text{ cm}^3 \text{ sec}^{-1}$ obtained, independent of ion kinetic energy. Several other exothermic negative ion-neutral reactions were also observed, including



The rate constants obtained for these processes are 4×10^{-9} , 2×10^{-11} , and $3.5 \times 10^{-11} \text{ cm}^3 \text{ sec}^{-1}$, respectively, and are independent of ion kinetic energy in the range from about 2 to

10 eV. The endothermic process $O^- + O_2 \rightarrow O_2^- + O$ was studied with the aid of isotopic labeling to determine the reaction mechanism. It was found that the rate coefficients for electron transfer and for atom transfer are in the ratio of 3 to 1 over the range of ion energies from about 2 to 10 eV. The rate for the overall process increased from 1.7 to $12 \times 10^{-11} \text{ cm}^3 \text{ sec}^{-1}$ in this energy range.

At Smithsonian Astrophysical Observatory, the excitation and deexcitation of metastable oxygen atoms (especially the ^1D level) in an electric discharge, and the processes by which fast photoelectrons convey their energy to the ionosphere are being investigated. It has been found that ^1D oxygen atoms react very rapidly with nitrogen molecules, so that most of them will be destroyed before radiating, if they are created in the atmosphere below about 150-km altitude.

At the Laboratory for Atmospheric and Space Sciences of the University of Pittsburgh, the construction of versatile laboratory systems equipped with sensitive diagnostic tools has permitted coordinated study by groups associated with Biondi, Donahue, Fite, Kaufman, and Zipf, of reaction rates for excitation and deexcitation suggested by field studies; examples follow. (1) The cross section for excitation of the Na D lines by vibrationally excited N_2 , H_2 , D_2 , and O_2 is being measured; cross section in N_2 is about $2 \times 10^{-15} \text{ cm}^2$. (2) The cross section for charge transfer from N_2^+ and O_2^+ to Na has been measured and the rate coefficients at thermal energies are estimated to be about $10^{-10} \text{ cm}^3 \text{ sec}^{-1}$. (3) The rate of formation of $O(^1S)$ and $O(^1D)$ atoms in dissociative recombination of O_2^+ has been measured as has the rate of quenching of these states by O_2 and N_2 . O_2 has been found to be very effective in quenching $O(^1D)$ and the high rates for quenching of $O(^1S)$ imply further difficulties in accounting for the nightglow green line. (4) The oscillator strengths of various transitions in O and N have been measured. In particular that of the $(2p)^4 \ 3p - (2p)^3 \ 3s \ 3S$ transition is 0.019. (5) Radiative and collisional lifetimes of electronically excited states are being measured by a modulated fluorescence technique. (6) An ultra-rapidly pumped flowing afterglow system elaborately equipped with diagnostic apparatus has been constructed to determine the temperature dependence of ion-molecule reactions and excitation processes. (7) Drift mobility tube studies are in progress to measure temperature dependence of ion-molecule reactions from 300° to 5000° K . (8) Recombination rates of electrons and diatomic ions are being measured over a wide range of electronic and ion temperature. Evidence has been obtained for rates increasing with vibrational excitation that can counteract the negative coefficient for the dependence on electron temperature.

The United Aircraft Research Laboratories are conducting studies to determine the collision frequency of electrons with alkali metal atoms and compounds that are typical contaminants present in re-entry wakes. These investigations involve the measurement of the collision frequency of electrons with sodium, sodium oxide, and sodium azide over the energy range 0.09 to 0.125 eV. From low-energy electron-sodium measurements conducted to date, it has been established that the effective collision frequency is relatively constant in the 0.09-to-0.125 eV energy range and significantly higher than that which would be predicted from extrapolation of existing high-energy cross-section information. This result is in substantial agreement with collision frequencies calculated on the basis of the theoretical analysis of low-energy electron-sodium collisional interactions presented by Garrett (Phys. Rev., 140, A705, 1965).

At the Aerospace Corporation, a rate of 2×10^{-15} molecules/ $\text{cm}^3 \text{ sec}$ at 300° K for the reaction $O_2(a^1\Delta_g) + O_3 \rightarrow 2 O_2 + O$ has been found by McNeal and Cook. The result confirms earlier suspicions that the reaction is partly responsible for discrepancies in the ozone

three-body formation rate determined from thermal decomposition and oxygen afterglow experiments. In the chemosphere the reaction can cause ozone decomposition, but at a rate small compared with the photodissociation of ozone.

At Grumman Aircraft Engineering Corporation, a small effort is continuing on the calculation of atomic collision rates. A phase of this project was completed with the calculation by Pomilla and others of a number of previously undetermined rates for collisions between hydrogen atoms, e.g., double-transition collisions, and single-transition collisions in which one atom is excited.

3. SOME THEORETICAL STUDIES OF ATOMIC AND MOLECULAR PROPERTIES

At the University of California, Berkeley, Space Sciences Laboratory, the new group working with Mittleman in theoretical atomic physics has as its object a general understanding of atomic and molecular interactions of importance in atmospheric and other applications.

Examples of the research follow: (1) Interaction of electrons with polar molecules, e.g., the minimum moment required to bind a charged particle to an extended dipole; (2) Statistical treatment of ionization in collisions between atoms; (3) Positronium formation in positron-hydrogen scattering; (4) The role of Rydberg states (molecular ion with a distant orbiting electron) in dissociative recombination; (5) Hamiltonian formulation of the many-electron problem in heavy atoms; (6) Shifts of highly excited atomic energy states caused by interaction with neighboring atoms or molecules, their relation to low-energy electron-atom scattering, and extension to electron scattering by diatomic molecules; (7) Rotational excitation of polar molecules by electrons; (8) A non-adiabatic approach to electron-alkali atom scattering; (9) Resonances in multichannel scattering; and (10) Resonances in proton-hydrogen and positron-hydrogen scattering.

In a systematic study, conducted by Benson and Berend of the Douglas Aircraft Company's Physical Sciences Department, of the kinetics of nonequilibrium phenomena of the upper atmosphere, a rigorous classical method was applied to calculate vibrational and rotational relaxation times of colliding diatomic molecules for arbitrary realistic anharmonic interaction potentials. The theory was also applied to evaluate both elastic and inelastic collision cross sections of electrons and atoms. The approach entails a direct numerical integration of the classical equation of motion in two dimensions; the result is subjected to a quantum restriction. While previous work relating to a central potential around one molecule, provided a useful first-order approximation, the present work accounts for separation of all interacting atoms of the colliding molecules and, in considering the detailed structure, accounts for the dynamics of the process. For the case of N_2-N_2 collisions, six Morse-type potential functions are applied; the only free parameter is the range term "a." There has been no previous precise theoretical treatment of the vibrational excitation of electron - molecule collisions in two dimensions. The theory was applied to the evaluation of the ionization cross section of hydrogen atoms upon electron impact. The results surpass the accuracy of the Born approximation and show excellent agreement with experimental data.

4. NOTES ON INSTRUMENTS AND MEASUREMENT TECHNIQUES

Extreme-UV Optics and Sensors. The optical properties of evaporated Pt and ir films in the extreme ultraviolet are being studied at NRL. The reflectance of these two elements has a quite similar wavelength dependence versus wavelength characteristics although ir has a higher reflectance over the range 300 to 2000 Å. Also the dependence of reflectance on evaporation conditions is similar. For example, the speed of evaporation has very little effect on the reflectance while the substrate temperature has a large effect; the higher the temperature, the higher the reflectance for both metals. By controlling the thickness so that the films are not opaque, the reflectance is increased slightly over that of an opaque film due to interference. Reflectances of 25% for Pt and 30% for ir have been obtained at 550 Å.

The properties of channel multipliers, both the Bendix "channeltron" and those obtained from Mullard, are being studied. The results show that both detectors are suitable for use as counters from 1216 to 256 Å and probably to shorter wavelengths. There is evidence of fatigue in both the Bendix and the Mullard multipliers and the resulting changes in sensitivity are not reversible. In the case of the Bendix tube, the fatigue pattern seems to depend upon the total amount of charge collected. There is not enough information now available to determine the parameters of the Mullard tube that contribute to the fatigue.

Research on gratings for the extreme ultraviolet, carried out by Bausch and Lomb for NRL, is continuing. Some of the techniques developed during the course of the work have been used in the ruling of two concave gratings with 1-m radius of curvature and 3600 lines/mm; these had comparatively high efficiencies in the first order at 304 Å.

Interferometry. AFCRL is continuing research on the use of interferometers and interpretation of interferometric data. The new far-infrared lamellar-grating spectrometer is being assembled and will shortly be installed in its new laboratory. It will be used to study the far-ir spectra of atmospheric gases, especially water vapor, and for other spectroscopic studies.

AFCRL is also developing a technique for handling interferograms obtained from an interferometer having some residual dispersion, a technique to measure directly the transfer function of an ir spectrometer using a lamellar-grating interferometer and an analysis of the effect of transforming an interferogram over an interval not symmetric with respect to the zero-path-difference abscissa. A real-time Fourier synthesizer was constructed and preliminary results on test functions have been obtained. A Möbius band interferometer that is immune to tilt and compensated for polarization effects was constructed and tested.

Chemiluminescent Research. A research program has been under way at AFCRL on infrared chemiluminescent reactions, to determine the energy distribution into internal modes and the efficiency of various mechanisms as ir emitters; the program uses interferometers, special integrating spheres, and novel electronic techniques. The $\Delta v = 1$ sequence of the OH radical, a primary radiator of the night airglow, formed by the reaction of $H + O_3$ has been observed. Infrared spectra of many of the nitrogen-oxygen reaction schemes are being obtained and interpreted. Near-resonant vibrational energy transfer has been studied in the $N_2 - CO$ vibrational system in order to be able to formulate a time-dependent description of radiating systems. Dipole moments of the more important radiating molecules are being studied both experimentally and theoretically. For comparison with other AFCRL results,

instruments, primarily interferometric spectrometers, are being developed that will be flown on a KC-135 aircraft to measure the infrared spectra of aurorae from high altitudes and latitudes.

Molecular Beams. To study the mechanisms of a collision between two molecules (atoms or ions) with relative energy of 1 to 10 eV, an extensive molecular-beam facility is being developed at AFCRL. This energy regime encompasses the binding energy of molecules and the activation energy of chemical reactions, ionization and excitation phenomena, and the relative energy at satellite velocities. Three techniques are presently under development to obtain the desired flux at these energies. The first is the use of the supersonic nozzle with a hot, light carrier gas such as H_2 "seeded" with the heavy molecule of interest. The second involves an important new idea in the use of a charge-exchange system. A plasma is used as the source of an ion beam whose space charge is partially neutralized by the presence of plasma electrons. This method eliminates the space-charge effects present in a pure ion beam that would limit the final intensity of the molecular beam. Using this new concept, a neutral beam has been produced with an average energy of 1 to 2 eV and intensity 10^{13} to 10^{14} particles/cm²/sec. This is a gain of at least 3 orders of magnitude in intensity over present state-of-the-art exchange beams.

The third method is an extremely simple concept. One takes a rifle bullet, hollows it out, fills it with a gas of interest, seals it with a membrane, fires it into a vacuum and stops the bullet while simultaneously rupturing the membrane. This single shot of gas can have a very large flux and even a .22-calibre rifle will attain 3 km/sec (energy is dependent, of course, on the mass of the species). Light-gas guns in hypervelocity ranges can accelerate sabots to 10 km/sec and a design study shows a flux of 10^{25} particles/cm²/sec to be feasible. This system has been named the AFCRL MASS beam for Mechanically Accelerated Sabot System. It is clear that by controlling the time of acceleration the state of the gas can be controlled.

At General Dynamics Convair Division a technique called merging beams has been developed for measuring two-body collision cross sections from thermal energy to several keV. Two molecular beams are merged and move in the same direction along a common axis. With this method, the two beams, each with a relatively high laboratory energy (several keV) and a modest energy spread (1.5 eV), can be used to produce low interaction energies (e.g., 0.25 eV) with a correspondingly low interaction energy spread (0.015 eV). The technique is valuable because it is the only method for obtaining direct measurements of reaction rates in an energy range of about 0.1 to 2 eV. This range is important, for example, in studies of the ionosphere, a disturbed atmosphere, and wakes and boundary layers of re-entry vehicles.

Studies using crossed molecular beams of neutral-neutral interactions at thermal energies have also been conducted. The purpose has been to measure interatomic potentials of systems that could be important in fuels used for propulsion of aerospace vehicles.

Passive Microwave Radiometry. The Space Sciences Department of Douglas Aircraft is investigating the utility of passive microwave-radiometry measurements to determine atmospheric properties, sea state, and sea-surface temperatures from spacecraft. In the past, a two-channel radiometer was flown over ocean and land surfaces at altitudes up to 11,000 m and the thermal emissions from the surfaces and the atmospheres were measured. The radiometer measured the cross-polarized thermal emission of electromagnetic radiation at wavelengths 1.35 and 1.90 cm. These data are being used in conjunction with theoretical studies

to develop remote-measurement techniques. The major portion of the outgoing microwave radiation in Earth's atmosphere originates from surface thermal emission. A recent study indicates how the water-surface emission depends upon wavelength and changes in water temperature.

Neutron-Activation Analysis of Remote Surfaces. In the past year, a joint effort of the Department of Nuclear Engineering and Space Sciences Laboratory, University of California, Berkeley, has been devoted to investigating the advantages and disadvantages of using lithium-drifted germanium detectors to observe the gamma rays produced by inelastic neutron scattering or activation. The germanium detectors should have several advantages over the scintillation counters used in previous mock-up experiments: (1) The better resolution of the germanium detectors will make it possible to observe weaker gamma rays since the same number of counts is concentrated in a smaller energy (i.e., voltage) interval. The use of germanium detectors might thus make it possible to observe less abundant elements on the remote surface. (2) The ability to resolve gamma rays with energies that are closer together may make it possible to identify more elements by means of their gamma-ray spectra than has heretofore been possible.

Before these advantages can be usefully employed, several questions must be answered. Perhaps the most important one is whether germanium detectors can be used in the presence of a strong neutron flux. In the spring and summer of 1965, a number of experiments were performed to determine whether germanium detectors could detect gamma rays of various intensities in the presence of a 14.0-MeV neutron flux. It was shown that the germanium crystals are actually not quite as good as sodium iodide scintillation counters under similar circumstances. The background pulses caused by the 14.0-MeV neutrons—probably inelastic scattering in germanium—were somewhat more numerous than the gamma-ray pulses when compared with the NaI case. At the present time, these experiments are being continued using neutrons having lower energies. It is probable that the situation may be somewhat improved in the lower energy region due to the decrease in inelastic scattering. The 14.0-MeV experiments have been conducted by Gray and the present work is being carried out by Kopchinski.

Another important problem arises from the fact that germanium crystals—to be useful—must be kept at liquid-nitrogen temperatures. This necessitates rather bulky and complex mountings for the detector. Several experiments are under way to improve the crystal-holder design. One is to try to eliminate the vacuum system used in the present holder by putting the crystal in a dry helium atmosphere. Several mounts have been built and they will be tried in the near future. This work is also being conducted by Kopchinski.

Satellite Gas-Surface Experiments. A set of three gas-surface experiments is being prepared by General Dynamics Convair for flight on the Orbiting Geophysical Observatory (OGO-F) to be launched in 1968. The experiments are concerned with the transfer of kinetic energy between a surface and the upper atmosphere. A temperature-sensitive probe having a threshold of $10 \mu\text{W}/\text{cm}^2$ will be used. Measurements will be made on the kinetic-energy flux of the upper atmosphere and the energy-accommodation coefficient of gold and aluminum.

Transient Gas Pressure Measurements. A gauge has been developed by the Research Department of Grumman Aircraft that is particularly suited to measuring transient gas pressures, such as gas bursts expanding into a vacuum. A commercial five-element subminiature vacuum tube is employed as basic element. Calibration curves for helium, nitrogen, neon,

argon, krypton, and xenon at room temperature were published by Valsamakis (Rev. Sci. Instr. **37**, 1318, 1966).

X-Ray Spectrograph. A laboratory feasibility study of a fast x-ray spectrograph for 1% energy resolution of x rays between 0.3 and 8 keV was successfully completed by Lockheed.

Radiation Sensor Research. The Douglas Aircraft Space Sciences Department has developed hardware and procedures for construction and testing of specific charged-particle experiments. Vacuum methods and chambers for long-duration tests of silicon detectors were developed. A dual-channel, coincident-pulse generator was built for simulation of particle pulses to the charge-sensitive preamplifiers. A scattering chamber particularly suited for calibration of detection systems was built. A computer program was written that calculates energy losses by charged particles in each detector of a range-energy telescope with as many as ten detectors and intervening absorbers. The problem of calculating the contribution to the telescope geometry factor from elements of solid angle $d\Omega(\theta)$ as a function of θ , the angle between the axis and $d\Omega$, was solved also. This relationship is important in order to evaluate the error in the energy measurement for particles that traverse the telescope at large θ . Electromagnetic radiation sensors for uv, x-, and gamma-ray measurements are also under study to provide an established, specialized capability for sensing and calibrating such radiation by means of both dispersive and nondispersive instruments for space experiments.

Comparisons and Calibrations. A comparison of two absolute radiant flux detectors was made by NBS in the spectral region 500 to 100 Å. One is a thermopile, the other is a rare-gas ionization counter. This work is now providing detector standards to NASA and its contractors so that their observations on the uv radiation from the Sun can be put on an absolute scale.

The NBS synchrotron was used to calibrate the response of particle detectors to low-energy electrons. These detectors will be used by NASA to measure the radiations present in the upper atmosphere and in space in their future rocket and satellite programs.

A significant advance in laboratory calibration techniques for space-flight instruments was accomplished by a cross-calibration of laboratory xuv monochromators between AFCRL and the Culham Laboratory, UKAEA, England. A comparison of the two independently calibrated monochromators was made at AFCRL, utilizing the same AFCRL hollow-cathode xuv light source.

5. OTHER DEVELOPMENTS

Effects of the Space Environment. NBS has started preliminary work to develop dosimetry techniques and standards for the GSFC accelerator laboratory as well as a method to simulate in the laboratory the natural and artificial electron spectrum of the Earth's magnetosphere. Efforts are also being directed toward radiation effects on electronic components and the cutoff thicknesses of satellite skins.

An NBS program on penetration of high-energy radiation through matter is being directed toward charged particles and bremsstrahlung encountered in a space environment. Calculations

for aluminum and tungsten absorbers for 100-keV and 10-MeV electrons are showing satisfactory agreement with available experimental data. The energy dissipation by electrons in the Earth's atmosphere has been calculated, taking into account the density variation of the atmosphere with height and the influence of the Earth's magnetic field. This information will provide a better understanding of the natural aurora and assist in the interpretation of auroral studies to be carried out with satellites.

A NASA Marshall Space Flight Center experiment, carried on each of the three Pegasus spacecraft (launched February 16, 1965, May 25, 1965, and July 30, 1965), monitored the surface degradation of certain thermal-control coatings. As a result of combined vacuum and uv effects, the ratios of solar absorptance to total emittance for these coatings changed in the following manner: (1) ZnO in methyl silicone, a 60% increase; (2) TiO_2 in methyl silicone, a 90% increase; (3) ZnO in potassium silicate, no change; (4) Alodine surface conversion on aluminum, a 10% increase.

Shielding of space vehicles from charged-particle radiation through the use of magnetic fields created by superconducting coils has great operational interest, if practical difficulties can be overcome. Northrop Corporation is studying the mechanics of charged-particle motion in the presence of magnetic fields, both analytically and experimentally using a magnetic-field simulation facility. Studies to date have provided information on totally forbidden volumes resulting from various magnetic-coil configurations. This investigation is now being extended to studies of the distribution in space of partially shielded regions near the magnets. These techniques are also of interest in connection with studies of the penetration of solar-flare protons into the Earth's magnetic field and their distribution in space in the vicinity of the Earth.

Data Encoding and Compression. Sakrison and Algazi of the Department of Electrical Engineering at Berkeley have devoted attention to the development of a source-encoding or "data-compression" method for counting-rate sources encountered in space experiments. The objective is to obtain a low data rate at the transmitter while preserving the features of the data of interest to experimenters. It is contemplated that such a source-encoding algorithm would be implemented on a small general-purpose digital computer of the type being considered for use on board a satellite. The theoretical aspects of this code stem from the work of Shannon on the relation of the information rate to the distortion in the transmission of analog messages by digital means. A situation is considered in which noisy data are obtained in a space experiment. A noise-dependent distortion measure is proposed which assesses realistically for such a noise-corrupted data source the preservation of the features of the data of interest to the experimenter. For this distortion measure a source code has been developed with the following major feature of importance in space experiments: The structure of the code has a limited dependence on the statistics of the data and, further, the distortion will remain fixed for changing source statistics. The received data can be used to monitor the behavior of the code and the code can be modified to adapt to new conditions.

The coding algorithm has been programmed and run on a small digital computer to study problems associated with implementation. Trial runs have been carried out with data obtained in a space experiment for which the information rate obtained is only 80% higher than the theoretical minimum predicted from Shannon's coding theorem.

An investigation is being conducted at the McDonnell Company to determine the amount of redundancy in manned space-flight telemetry data. The flight of Gemini 12 (1966-104A) is being evaluated using various redundancy-removal algorithms to determine specifications for

a telemetry system for manned interplanetary missions. Initial results indicate a 100-to-1 improvement in the use of the radio-frequency spectrum, with attendant reductions in power, weight, and data processing. Future work will include examination of voice communications and television redundancies in an attempt to design a complete self-adaptive telecommunications system.

Passive Attitude Stabilization by Wires. An analytical study by Newton at APL has found that the attitude of a satellite can be made stable in all three libration angles by a suitable arrangement of wires rather than rigid members to give the necessary vertical extent. In one stabilization method, four wires are connected to the main satellite body at points as far apart as possible. The other ends of the wires are connected to a small mass, yielding a pyramidal configuration. The normal modes of libration and the response to perturbing torques of such a satellite have been analysed. It is shown that the long axis of the main body should point in the direction of motion. That is, the main body should be held in a position of unstable equilibrium. It is also shown that the effects of radiation pressure and of thermal distortion are an order of magnitude smaller than for equivalent satellites using rigid structures.

Propagation of Waves of Ionization in Gases Induced by Microwaves. In studies by Bethke and others at General Electric's Missile and Space Division, it has been found that if a localized low-electron-density plasma is exposed to sufficient microwave radiation, the plasma electron density will increase and propagate toward the radio-frequency source as an ionization wave. Thus far, these studies have employed 8.35-GHz microwave irradiation of xenon, krypton, and argon (0.3 to 3.0 torr) localized plasmas in 5-cm inside-diameter cylindrical test sections, with suitable instrumentation for monitoring incident radio-frequency power, reflected amplitude, and reflected Doppler shift. The ionization waves are further monitored with optical, high impedance, and $\vec{v} \times \vec{B}$ probes, and with a 60-GHz microwave interferometer. Ionization waves have been produced in these gases through the radio-frequency power range of ~ 0.15 to ~ 30 watts cm^{-2} , producing velocities which range from $\sim 10^3$ to $> 10^6$ cm/sec, respectively. Maximum electron densities range from ~ 1 to > 10 times the critical electron density. For most of the gas-pressure combinations investigated, there appear to be two modes of propagation, with distinct curves for high radio-frequency power and low radio-frequency power versus velocity. Ionization-wave-mechanism investigations in the higher radio-frequency power versus velocity mode have led to the conclusion that ionization-wave formation in rare gases is due to a multiple step electron-collision mechanism involving metastable excited atoms, while ionization-wave propagation is initially due to a multiple step radiative mechanism, also involving the metastable state.

Development of Space Disturbance Forecast Services. Space Disturbance Forecast Services of ITSA/ESSA were materially improved during 1966. The major improvements were: (1) Nearly continuous coverage of the Sun by globally-dispersed cooperating solar observatories, reporting on visually observed events, rather than from film records; (2) A rapid reporting system whereby major solar events were immediately reported and transmitted to the forecast centers on a priority basis; (3) 24 hr/day monitoring of solar and related geophysical data to insure that appropriate groups are immediately advised of events of interest to them; and (4) Twice-daily issuance of one-to-three day forecasts of solar flare probability (by importance), Ottawa 10-cm solar-radio flux, and geomagnetic indices.

In addition to the above developments, an effective liaison was established between the major NASA space-program offices and the Space Disturbance Forecast Services office. This liaison was particularly effective in providing Space Environmental Forecast support to (1) Lunar Orbiters 1 and 2, (2) the last of the Gemini satellites, and (3) the OSO/OGO programs. These services were in direct support of satellite-sensor operation and lunar photography.

APPENDIX I

Satellite and Rocket Launchings in 1966

TABLE 1
U.S. SATELLITES AND SPACE PROBES OF SCIENTIFIC INTEREST
JANUARY 1966 - MARCH 1967

Scientific Designation	Popular Name	Lifetime (Launch-Decay)	Experiments	Initial Orbital Elements			
				Perigee (km)	Apogee (km)	Period (min)	Inclin. (degrees)
1966-8A	ESSA 1	2/ 3/66	Photography of Earth's cloud cover, first U.S. operational weather satellite	667	841	100.2	97.89
1966-16A	ESSA 2	2/28/66	Photography of Earth's cloud cover. APT system	1353	1413	113.42	101
1966-19A	Gemini Agena Target Vehicle	3/16/66	Target vehicle for rendezvous & docking with Gemini spacecraft	296	297	90.54	28.89
1966-20A	Gemini 8	3/16/66-3/17/66	Manned orbital flight, Niel A. Armstrong, David K. Scott. Rendezvous and docking with target vehicle	160	271	88.83	28.92
1966-25B	OV1-5	3/30/66	Measurements of uv-ir radiation	981	1054	104.4	144.7
1966-30A	Surveyor Model	4/ 8/66-5/ 5/66	Test capability to place Surveyor spacecraft in lunar-transfer trajectory	185	333	89.76	30.77
1966-31A	QAO-1	4/ 8/66	To study celestial objects in the ultra-violet, x-ray and gamma ray regions	798	808	101	35
1966-34A	OV3-1	4/22/66	Measurements of protons, electrons and plasma	352	5709	151.7	82.5
1966-40A	Nimbus 2	5/15/66	Photography of Earth's cloud cover; measurement of infrared radiation. APT system	1003	1178	108	100
1966-44A	Explorer 32 (AE-B)	5/25/66	To measure temperature composition, densities and pressures in the upper atmosphere	290	2710	116	64.6
1966-45A	Surveyor 1	5/30/66-6/ 2/66	Television photography of lunar surface	Soft landing on moon at 0617 UT, 2 June 1966, at 2.49°S lunar latitude, 43.32°W lunar longitude			
1966-46A	Atlas/ATDA	6/ 1/66-7/11/66	Target vehicle for rendezvous and docking with Gemini spacecraft	296	297	90.5	28.88
1966-47A	Gemini 9	6/ 3/66-6/ 6/66	Manned orbital flight, Thomas P. Stafford, Eugene A. Cernan. Rendezvous and docking with target vehicle	161	275	90	28.88

U.S. SATELLITES AND SPACE PROBES OF SCIENTIFIC INTEREST
JANUARY 1966 - MARCH 1967
(continued)

Scientific Designation	Popular Name	Lifetime (Launch-Decay)	Experiments	Initial Orbital Elements			
				Perigee (km)	Apogee (km)	Period (min)	Inclin. (degrees)
1966-49A	OGO-3	6/ 7/66	Twenty-one experiments to measure and investigate magnetic and electrical fields, energetic particles, ionospheric composition, micrometeoroids and radio emissions	273	121,937	1738	30.9
1966-52A	OV3-4	6/10/66	Radiation research	641	4723	143.2	40.8
1966-56A	PAGEOS 1	6/24/66	Passive geodetic satellite	4210	4263	181.3	86.97
1966-58A	Explorer 33 (IMP-4)	7/ 1/66	Measurements of magnetic fields, solar plasma, and energetic particles in cislunar space	30,532	494,230	324.8 hours	29
1966-59A	Upgraded Saturn 1	7/ 5/66	Engineering test vehicle	188	189	88.3	32
1966-65A	Agena 10	7/18/66-12/29/66	Target vehicle for rendezvous & docking with Gemini spacecraft	302	310	90	28.87
1966-66A	Gemini 10	7/18/66-7/21/66	Manned orbital flight, John W. Young, Michael Collins. Rendezvous and docking with target vehicle. Extra-vehicular activity. Sixteen experiments.	165	274	88.8	28.9
1966-70A	OV3-3	8/ 4/66	Radiation research	352	4448	136.6	81.6
1966-73A	Lunar Orbiter 1	8/10/66-10/29/66	Television photography of lunar surface. Meteoroid measurements. Selenodesy.	189	1868	217.6	12.2
1966-75A	Pioneer 7	8/17/66	Space probe to measure radiation, particles and magnetic fields in space.	(Heliocentric orbit)			
1966-80A	Gemini Agena Target Vehicle	9/12/66-12/30/66	Target vehicle for rendezvous and docking with Gemini spacecraft	290	307	90.5	28.88
1966-81A	Gemini 11	9/12/66-9/15/66	Manned orbital flight, Charles Conrad, Richard F. Gordon. Rendezvous and docking with target vehicle. Extra-vehicular activity. Eleven experiments.	161	281	89	28.87
1966-84A	Surveyor 2	9/20/66-9/23/66	Television photography of lunar surface.	Impacted on Moon at 0318 UT, 23 September 1966, at 4° N, 11° W lunar coordinates.			

U.S. SATELLITES AND SPACE PROBES OF SCIENTIFIC INTEREST
JANUARY 1966 - MARCH 1967
(continued)

Scientific Designation	Popular Name	Lifetime (Launch-Decay)	Experiments	Initial Orbital Elements			
				Perigee (km)	Apogee (km)	Period (min)	Inclin. (degrees)
1966-87A	ESSA 3	10/ 2/66	Photography of Earth's cloud cover; measurements of infrared radiation	1383	1485	114.65	101.02
1966-95A	Surveyor Model	10/26/66-11/ 6/66	Test capability to place Surveyor spacecraft in lunar transfer trajectory	173	472,590	19,450	29.612
1966-96A	1st Intelsat 2	10/26/66	Communications satellite	191	20,604	681	26.6
1966-97A	OV3-2	10/28/66	Radiation research	319	1611	104.2	82.0
1966-100A	Lunar Orbiter 2	11/ 6/66	Television photography of lunar surface.	40	1858	208.5	11.8
			Meteoroid measurements. Selenodesy.				
1966-103A	Gemini Agena Target Vehicle	11/11/66-12/23/66	Target vehicle for rendezvous and docking with Gemini spacecraft	294	303	90.2	28.88
1966-104A	Gemini 12	11/11/66-11/15/66	Manned orbital flight, James A. Lovell, Jr., Edward E. Aldrin. Rendezvous and docking with target vehicle.	160	270	88.7	28.88
			Extra-vehicular activity. Fourteen experiments				
1966-110A	ATS-1	12/ 7/66	Experiments in spacecraft communications, meteorology and control technology. Measurements of orbital environment.	35,850	36,888	1466	0.23
1966-111A	OV1-9	12/11/66	Measurement of protons and electrons	477	4806	142.3	99.4
1966-111B	OV1-10	12/11/66	Radiation research. Measurement of magnetic field.	645	767	98.9	93.5
1966-114A	Biosatellite 1	12/14/66-2/15/67	Thirteen biological experiments to study effects of space environment on various life processes.	294	330	91	33.5
1967-1A	2nd Intelsat 2	1/11/67	Communications satellite	33,527	36,142	1386.6	2.2
1967-6A	ESSA 4	1/26/67	Photography of Earth's cloud cover. APT system	1323	1439	113.4	102

U.S. SATELLITES AND SPACE PROBES OF SCIENTIFIC INTEREST
JANUARY 1966 - MARCH 1967
(continued)

Scientific Designation	Popular Name	Lifetime (Launch-Decay)	Experiments	Initial Orbital Elements			
				Perigee (km)	Apogee (km)	Period (min)	Inclin. (degrees)
1967-8A	Lunar Orbiter 3	2/ 5/67	Television photography of lunar surface. Meteoroid measurements. Selenodesy.	(Selenocentric orbit)			
1967-20A	OSO-3	3/ 8/67	Study solar x-rays, gamma rays and ultra-violet radiation.	542	569	95.8	32.8
1967-26A	3rd Intelsat 2	3/23/67	Communications satellite	19,266	19,343	1434.5	1.4

TABLE 2
SUMMARY OF
SOUNDING-ROCKET LAUNCHINGS IN 1966

Type of Probe	Atmospheric Physics	Atmospheric Composition	Ionospheric Physics	Particles and Fields	Airglow and Aurora	Solar Physics	Astronomy	Micrometeorites	Other	TOTAL *
High-Altitude Probes 500-1015 km	1	2	5	2	2		1			7
Low-Altitude Probes < 500 km	73	15	57	23	15	30	11	3	9	184
Meteorological Rockets	1955									1955
TOTAL	2029	17	62	25	17	30	12	3	9	2146

* A few rockets carried instruments to investigate more than one kind of phenomenon and are counted in more than one column, but in the totals, this duplication is eliminated.

TABLE 3
HIGH ALTITUDE PROBES 1966

Date (UT)	Rocket Type or Number	Launching Locality	Atmospheric Physics	Atmospheric Comp.	Ionospheric Physics	Particles & Fields	Airglow and Aurora	Astronomy	Approx. Altitude (km)
1 May	AB 19.286	Fort Churchill				X	X		723
20 May	NASA 8.44GR	Wallops Island			X			X	918
28 Jun	AC 19.191	Wallops Island			X				562
12 Jul	NASA 8.12UA	Wallops Island			X		X		1,015
14 Jul	NC 20.189	Point Mugu		X					1,000
24 Sep	NASA 8.27IA	Wallops Island	V		X	X			884
6 Oct	NASA 8.38GI	Wallops Island		X	X				650

TABLE 4
SOUNDING-ROCKET LAUNCHINGS
1966

Date (UT)	Time (UT)	Rocket Number or Type	Launching Site	Experiments									Approx. Altitude (km)
				Atmospheric Physics	Atmospheric Composition	Ionospheric Physics	Particles and Fields	Airglow and Aurora	Solar Physics	Astronomy	Micrometeorite	Other (test)	
1966													
10 Jan	1714	NASA 14.248	Wallops Island			X							
17 Jan	2239	NASA 14.262CM	Wallops Island	V									206
18 Jan	0032	NASA 14.263CM	Wallops Island	V									205
18 Jan	0200	NASA 14.264CM	Wallops Island	V									167
18 Jan	0319	NASA 4.90GG	Wallops Island							X			134
18 Jan	0512	NASA 14.265CM	Wallops Island	V									207
18 Jan	1131	NASA 14.266CM	Wallops Island	V									213
23 Jan	0742	NASA 10.185CM	Fort Churchill	G									125
25 Jan	0152	NASA 10.158UA	Wallops Island	S									167
27 Jan	0129	NC 3.186	White Sands		X	X							243
1 Feb	1800	NE 3.156R	White Sands						X				209
1 Feb	2012	NASA 10.182CM	Point Barrow	G									117
1 Feb	2046	NASA 10.147CM	Wallops Island	G									118
2 Feb	0202	NASA 10.186CM	Fort Churchill	G									118
2 Feb	1005	NASA 4.50UG	White Sands							X			175
3 Feb	1831	NASA 10.159UA	Wallops Island	S									131
4 Feb	0154	NASA 10.143UA	Wallops Island	S									152
10 Feb	0542	NASA 14.188GE	Fort Churchill				X	X					178
10 Feb	0709	NASA 10.187CM	Fort Churchill	G									117
10 Feb	0748	NASA 10.148CM	Wallops Island	G									114
10 Feb	0800	NASA 10.183CM	Point Barrow	G									---
10 Feb	1800	NASA 10.145CM	Fort Churchill	G									122
10 Feb	1841	NASA 10.149CM	Wallops Island	G									114
10 Feb	2030	NASA 10.148CM	Point Barrow	G									---
10 Feb	2130	NASA 10.184CM	Point Barrow	G									---
17 Feb	0256	NASA 14.189GE	Fort Churchill				X	X					209
17 Feb	1616	NASA 14.243UE	Wallops Island			X							186
19 Feb	0105	AFS.502	Vega Baja, P.R.	V									192
20 Feb	0530	NASA 4.162UA	Fort Churchill				X	X					166
20 Feb	0645	AFS.505	Vega Baja, P.R.	V									192
21 Feb	1310	NC 7.181	Eglin		X								175
21 Feb	1957	NC 7.180	Eglin		X								188
21 Feb	2023	NC 7.178	Fort Churchill		X								196
27 Feb	1657	NASA 14.251UM	Ascension Isl.	I									131
2 Mar	1755	NASA 4.99DS	Wallops Island						X				228

Symbols for Type of Experiment

- C - Chaff: winds
G - Grenades: winds, temperature, pressure and density
I - Instruments on rocket: pressure, temperature and density
P - Parachute and instruments: winds, temperature and density
S - Falling sphere: winds, temperature and density
V - Vapor trail: winds
X - Other experiments

SOUNDING-ROCKET LAUNCHINGS
1966
(continued)

Date (UT)	Time (UT)	Rocket Number or Type	Launching Site	Experiments									Approx. Altitude (km)
				Atmospheric Physics	Atmospheric Composition	Ionospheric Physics	Particles and Fields	Airglow and Aurora	Solar Physics	Astronomy	Micrometeorites	Other (test)	
1966													
2 Mar	1800	NASA 8.25GA-GI	Wallops Island	X		X					X	496	
3 Mar	2154	NASA 4.100DS	Wallops Island						X			219	
8 Mar	0742	NASA 4.148CG	White Sands							X		165	
10 Mar	0945	AF7.327	Eglin	I								224	
14 Mar	0513	NASA 14.190GE	Fort Churchill				X	X				---	
23 Mar	0407	NASA 18.07GE	Fort Churchill				X	X				290	
30 Mar	0920	NB 20.152	Vandenberg		X			X				---	
30 Mar	1830	AF3.524	White Sands			X			X			240	
4 Apr	1652	NASA 14.216AI	Wallops Island			X						174	
8 Apr	0401	NASA 14.76UI	Wallops Island			X					X	159	
14 Apr	0555	NASA 18.08GE	Fort Churchill				X	X			X	296	
14 Apr	1500	NASA 4.143NA	White Sands		X			X				183	
14 Apr	1508	NASA 4.24US	White Sands						X			192	
21 Apr	1125	NASA 4.165UA	White Sands							X		154	
28 Apr	2335	NASA 4.189DS	White Sands						X			175	
29 Apr	0349	AD3.723	White Sands	X								175	
1 May	0630	AB19.286	Fort Churchill				X	X				723	
1 May	2210	NASA 10.190GM	Point Barrow	G								126	
2 May	0114	NASA 10.188GM	Wallops Island	G								131	
2 May	0232	NASA 10.192GM	Fort Churchill	G								79	
3 May	2201	NASA 10.191GM	Point Barrow	G								126	
4 May	0008	NASA 10.193GM	Fort Churchill	G								123	
4 May	0037	NASA 10.189GM	Wallops Island	G								119	
9 May	1520	NASA 4.106NP	White Sands								X	174	
18 May	0402	NASA 4.171UC	Wallops Island							X		210	
20 May	0800	NASA 15.26GI	36°46'N 21°57'E			X						---	
20 May	0800	NASA 15.27GI	36°46'N 21°57'E			X						---	
20 May	0930	NASA 15.28GI	36°46'N 21°57'E			X						---	
20 May	1015	NASA 15.29GI	36°46'N 21°57'E			X						---	
20 May	1106	NASA 15.30GI	36°46'N 21°57'E			X						---	
20 May	1510	NASA 4.95GS	White Sands						X			172	
20 May	1904	NASA 8.44GR	Wallops Island			X				X		918	
20 May	2330	NASA 4.92GS	White Sands						X			195	
21 May	0930	NASA 15.31GI	36°46'N 21°57'E			X						---	
24 May	0507	NASA 4.51UC	White Sands						X			132	
14 Jun	0918	NASA 14.270UI	Wallops Island			X						186	
17 Jun	0313	NASA 10.198GM	Fort Churchill	G								---	
17 Jun	0319	NASA 10.196GM	Point Barrow	G								---	
18 Jun	0125	AF6.501	Eglin	VG								240	
23 Jun	0635	NASA 10.199GM	Fort Churchill	G								---	
23 Jun	0752	NASA 10.197GM	Point Barrow	G								---	
23 Jun	0953	AF7.621	Eglin	VG								175	
25 Jun	0130	AF7.506	Eglin			X	X					192	
25 Jun	0336	AF7.509	Eglin		X							159	
25 Jun	0815	AF7.620	Eglin		X							143	
25 Jun	0957	AF7.507	Eglin			X	X					192	

SOUNDING-ROCKET LAUNCHINGS
1966
(continued)

Date (UT)	Time (UT)	Rocket Number or Type	Launching Site	Experiments									Approx. Altitude (km)
				Atmospheric Physics	Atmospheric Composition	Ionospheric Physics	Particles and Fields	Airglow and Aurora	Solar Physics	Astronomy	Micrometeorites	Other (test)	
1966													
28 Jun	1723	AC19.191	Wallops Island			X							562
11 Jul	1918	NASA 14.96UA	Fort Churchill		X	X							202
12 Jul	2100	NASA 8.12UA	Wallops Island			X		X					1015
14 Jul	1010	NC 20.189	Point Mugu		X								1000
14 Jul	1515	NASA 14.166II	Wallops Island			X							195
16 Jul	0532	NASA 4.159GG	White Sands								X		145
17 Jul	0056	NASA 14.291CH	Wallops Island	V									192
17 Jul	0500	NASA 14.292CH	Wallops Island	V									211
17 Jul	0645	NASA 14.293CH	Wallops Island	V									199
17 Jul	0825	NASA 14.294CH	Wallops Island	V									200
17 Jul	0908	NASA 14.295CH	Wallops Island	V									208
20 Jul	1950	NASA 14.218GE	Fort Churchill				X						---
22 Jul	2102	AF3.525	White Sands			X			X				256
27 Jul	1500	NE 3.190	White Sands							X			211
1 Aug	1900	[AFCRL]	White Sands	S									---
1 Aug	2200	[AFCRL]	White Sands	S									---
6 Aug	0800	[AFCRL]	White Sands	S									---
6 Aug	1100	[AFCRL]	White Sands	S									---
7 Aug	0700	NASA 14.296GH	Wallops Island	G									114
7 Aug	0904	NASA 10.2026GH	Fort Churchill	G									---
7 Aug	0949	NASA 14.289UM	Fort Churchill	I									---
7 Aug	1735	NASA 10.203GH	Fort Churchill	G									---
7 Aug	2046	NASA 10.206GH	Wallops Island	G									---
8 Aug	1920	AE3.734	Fort Churchill				X						127
11 Aug	1732	AC3.364	Fort Churchill					X					207
14 Aug	2035	NASA 10.200GH	Point Barrow	G									---
15 Aug	0808	NASA 10.201GH	Point Barrow	G									---
15 Aug	1828	NASA 8.32DA	Wallops Island		X	X							466
15 Aug	2135	NASA 14.170UA	White Sands								X		160
17 Aug	1950	NASA 17.02GT	Wallops Island			X			X			X	358
24 Aug	2100	NASA 14.183UE	Fort Churchill			X	X		X				157
24 Aug	2315	NASA 14.271UI	Wallops Island			X							164
25 Aug	0045	NASA 14.272UI	Wallops Island			X							169
26 Aug	1813	NASA 4.101DS	Wallops Island						X				211
26 Aug	1831	NASA 18.05GA	Wallops Island	I	X	X							287
26 Aug	1851	NASA 18.06GA	Wallops Island	I	X	X							308
26 Aug	1911	NASA 14.285UM	Wallops Island	I									149
28 Aug	0423	NASA 14.286UM	Wallops Island	I									140
28 Aug	0700	NASA 18.22GA	Wallops Island	I	X	X							301
29 Aug	1238	NASA 15.12GI	White Sands			X							---
29 Aug	1337	NASA 15.11GI	White Sands			X							---
29 Aug	1520	NASA 4.156GH	White Sands			X		X					206
1 Sep	1858	NASA 18.18UE	Fort Churchill				X						242
2 Sep	1600	NASA 14.219GE	Fort Churchill				X						---
2 Sep	2227	NASA 14.220GE	Fort Churchill				X						149

SOUNDING-ROCKET LAUNCHINGS
1966
(continued)

Date (UT)	Time (UT)	Rocket Number or Type	Launching Site	Experiments									Approx. Altitude (km)
				Atmospheric Physics	Atmospheric Composition	Ionospheric Physics	Particles and Fields	Airglow and Aurora	Solar Physics	Astronomy	Micrometeorites	Other (test)	
1966													
2 Sep	2250	NA 3.182	White Sands							X		206	
3 Sep	1724	NASA 14.221GE	Fort Churchill				X					160	
6 Sep	1226	NASA 18.20UE	Fort Churchill				X					238	
6 Sep	1804	NASA 18.21UE	Fort Churchill				X					243	
14 Sep	0135	NASA14.278CA-CI	Fort Churchill	V		X						161	
14 Sep	0400	NASA14.279CA-CI	Fort Churchill	V		X						186	
16 Sep	0122	NASA14.280CA-CI	Fort Churchill	V		X						185	
16 Sep	0300	NASA14.281CA-CI	Fort Churchill	V		X						185	
16 Sep	0417	NASA14.282CA-CI	Fort Churchill	V								206	
16 Sep	1554	NASA 14.164UI	Wallops Island			X					X	166	
17 Sep	0253	NASA 18.19UE	Fort Churchill				X					243	
20 Sep	0545	NASA 4.176UG	White Sands							X		165	
24 Sep	0913	NASA 8.27IA	Wallops Island	V		X	X					884	
25 Sep	0951	NASA 18.26IA	Wallops Island	V		X	X					280	
28 Sep	1816	AC17.604D	Fort Churchill			X		X				127	
30 Sep	1835	NASA 10.146GM	Wallops Island	G								118	
30 Sep	2350	NASA 14.217GM	Wallops Island	G								153	
1 Oct	0530	NASA 10.209GM	Wallops Island	G								115	
1 Oct	1127	NASA 10.210GM	Wallops Island	G								126	
4 Oct	2029	NA 3.160	White Sands						X			154	
6 Oct	2029	NASA 8.38GI	Wallops Island		X	X						650	
10 Oct	1757	AF7.348	Eglin	S								192	
11 Oct	2322	KP 3.16	White Sands					X				---	
12 Oct	0152	NASA 4.149CG	White Sands							X		144	
14 Oct	1820	AE7.813	Eglin			X						159	
22 Oct	1520	NASA 4.161NA	White Sands								X	149	
25 Oct	1725	NASA 4.195GA-GI	White Sands			X					X	186	
25 Oct	1810	NASA 10.181AI	White Sands			X						119	
30 Oct	1506	AC6.710	Eglin					X				95	
5 Nov	1455	[AFCLRL]	Brazil			X			X			---	
8 Nov	1732	NASA 18.04GE	Wallops Island			X	X				X	216	
11 Nov	0434	NASA 14.287IE	Fort Churchill				X				X	193	
12 Nov	1200	[Sandia]	Cassino						X			250	
12 Nov	1338	[BRL]	Cassino			X						85	
12 Nov	1354	[AFCLRL]	Cassino			X			X			115	
12 Nov	1402	NASA14.77CA-CI	Cassino	V		X						185	
12 Nov	1406	NASA 14.274UI	Cassino			X			X			197	
12 Nov	1407	[Sandia]	Cassino						X			250	
12 Nov	1407	[BRL]	Cassino			X						85	
12 Nov	1408	NASA 14.302UI	Cassino			X			X			160	
12 Nov	1408	[AFCLRL]	Cassino			X			X			115	
12 Nov	1410	NASA 14.304UI	Cassino			X			X			195	
12 Nov	1429	[AFCLRL]	Cassino			X			X			115	
12 Nov	1445	[Sandia]	Cassino						X			250	
12 Nov	1450	[BRL]	Cassino			X						85	
12 Nov	1535	[BRL]	Cassino			X						85	

SOUNDING-ROCKET LAUNCHINGS
1966
(continued)

Date (UT)	Time (UT)	Rocket Number or Type	Launching Site	Experiments									Approx. Altitude (km)	
				Atmospheric Physics	Atmospheric Composition	Ionospheric Physics	Particles and Fields	Airglow and Aurora	Solar Physics	Astronomy	Micrometeorites	Other (test)		
1966														
12 Nov	1600	NASA 14.303UI	Cassino				X			X				200
12 Nov	1615	NASA 4.153GS	White Sands							X				151
12 Nov	1640	NASA 4.191DS	White Sands							X				174
21 Nov	1000	NASA 4.154GG	White Sands									X		165
27 Nov	0216	AG 3.257	Fort Churchill									X		192
30 Nov	1145	NASA 4.181UA	White Sands	X	X									219
30 Nov	1906	NASA 18.27UE	Wallops Island			X	X			X				359
2 Dec	2109	NASA 4.180	White Sands	X	X									227
6 Dec	0353	AE 3.724	White Sands	X									X	208
13 Dec	0630	NASA 4.182UC	Natal									X		169
14 Dec	0816	AC 15.735	Fort Churchill					X	X					224
14 Dec	0816	AF 3.615	Fort Churchill			X			X					192

APPENDIX II

**Planned Satellite
and Rocket Launchings in 1967**

TABLE 1
 PLANNED SATELLITE AND SPACE PROBE LAUNCHINGS IN 1967
 IN U.S. SPACE RESEARCH PROGRAM

Spacecraft	Primary Experiments	No. of Launches
Orbiting Solar Observatory (OSO)	Solar physics, primarily (Chapter 4, Section 4)	2
Orbiting Geophysical Observatory (OGO)	Particles and fields, neutral and ion composition of upper atmosphere, electromagnetic energy sources (Chapter 5, Section 1)	2
Explorers		
Interplanetary Monitoring Platform (IMP)	Particles and fields, micrometeorites, figure of the Moon (Chapter 5, Section 1)	1
Injun Explorer	Precipitated and trapped radiation, VLF emissions in ionosphere (Chapter 5, Section 1)	1
Owl Explorer	Aurora and airglow, correlated with precipitated and trapped radiation (Chapter 5, Section 1)	2
Radio Astronomy Explorer (RAE)	Radio signals from celestial sources, 0.25 to 9.2 MHz (Chapter 3, Section 4)	1
NRL/NASA Solar Explorer (Solrad)	Solar x-ray emission monitoring (Chapter 4, Section 2)	1
Air Density Explorer	Inflatable sphere (Chapter 6, Section 3)	1
Orbiting Vehicle (OV) Series		
OV1-11	Electromagnetic radiation, particle fluxes and spectra, O ₂ and O ₃ profiles (Chapter 6, Section 3)	1
OV1-86	Interferometer, radiometers, cosmic-ray telescope (Chapter 6, Section 3)	1
OV1-13	Cosmic rays, solar cells, space material effects	1
OV1-14	Particles and fields, Lyman- α (Chapter 5, Section 1)	1
OV2-5	Particles and fields, VLF signals, Lyman- α (Chapter 5, Section 1)	1
OV3-5	Atmospheric composition	1
OV3-6	Latitudinal atmospheric structure	1

PLANNED SATELLITE AND SPACE PROBE LAUNCHINGS IN 1967
IN U.S. SPACE RESEARCH PROGRAM
(continued)

Spacecraft	Primary Experiments	No. of Launches
OV5-1	Solar flare studies	1
OV5-2	Proton and electron flux and spectra	1
OV5-3	Space vacuum friction	1
OV5-4	Zero-gravity liquid heat transfer	1
OV5-5	VLF plasma waves	1
Pioneer	Particles, fields and electron density in interplanetary space, and cosmic dust (Chapter 6, Section 1)	1
Mariner	Environment of Venus, interplanetary medium, celestial mechanics (Chapter 8, Section 3)	1
Lunar Orbiter	Lunar photography, lunar gravitational field (Chapter 8, Section 1)	3
Surveyor	Television photography and sampling of lunar surface (Chapter 8, Section 1)	5
Biosatellite	Effects of space environment on biological systems (Chapter 9, Section 2)	1
Nimbus	Global cloud-cover and ir photography, solar uv flux, meteorological studies (Chapter 7, Section 1)	1
Applications Technology Satellite (ATS)	Communications, gravity-gradient stabilization, meteorology, space effects on materials, cosmic radio noise, electric fields, VLF power spectrum, energetic particles (Chapter 7, Section 1; Chapter 11, Section 1)	1

TABLE 2
PLANNED SOUNDING-ROCKET LAUNCHINGS
BY NASA IN 1967

<u>INSTITUTION</u>	<u>INVESTIGATOR</u>	<u>EXPERIMENT</u>	<u>LAUNCH SITE*</u>
Cornell University	M. Harwit	IR stellar spectra	WS
GSFC	T. L. Aggson	Instrumentation test	WI
University of New Hampshire	J. A. Lockwood	Latitudinal survey of cosmic-ray neutrons, charged particles and x-ray flux	WI, FC, & Brazil
GSFC	O. E. Berg	Electron and micrometeorite density, and airglow	WS
GSFC	E. J. Maier	Electron and ion composition, temperature, and density	WI
ESSA	E. Whipple	Local electron density and magnetic field in the ionosphere	WS
AS&E	R. Giacconi	Location and intensity of celestial x-ray sources	WS
Princeton University	D. C. Morton	UV stellar spectra, search for interstellar H	WS
GSFC	T. Stecher	UV radiation from early-type stars	WS
Dudley Observatory	C. L. Hemenway	Micrometeorite particles and dust collection and analysis	WS
University of Minnesota	P. J. Kellogg	Electric and magnetic field variations in the magnetosphere	WI
NRL	E. T. Byram	Stellar spectra in Orion region	WS
GSFC	R. G. Stone	Cosmic radio noise background at low frequencies	WI
University of Michigan	E. J. Schaefer	Atmospheric composition	FC
GSFC	J. A. Kane	Correlation of D-region electron density and noctilucent clouds	PB Norway
GSFC	F. A. Volpe	Test flight of Fine Attitude Control System (FACS)	WS
University of Hawaii	H. C. McAllister	Atmospheric absorption and solar spectroscopy	WS

* See end of Table 3 for explanation of abbreviations.

PLANNED SOUNDING-ROCKET LAUNCHINGS
BY NASA IN 1967
(continued)

<u>INSTITUTION</u>	<u>INVESTIGATOR</u>	<u>EXPERIMENT</u>	<u>LAUNCH SITE</u>
Ames	N. H. Farlow	Micrometeorite collection	WS
University of Minnesota	A. O. C. Nier	Neutral composition profiles of the atmosphere	WS
AS&E	J. R. Waters	Flight test directional neutron detector developed for OGO	WI
Rice University	B. J. O'Brien	Origins of particles that cause aurora	FC
NRL	R. Tousey M. J. Koomen	Measure solar flux at Lyman- α	WS
GSFC	J. H. Underwood	Solar x-rays during solar eclipse	WS
GCA	L. G. Smith J. F. Bedinger	Luminescent clouds and the ionosphere during solar eclipse	Brazil
University of Illinois	S. A. Bowhill	Electron density and neutral atmosphere in lower ionosphere	Brazil
University of Maryland	R. T. Bettinger	Electron energy distribution in the ionosphere	WI
NCAR	E. A. Martell	Air samples collected to determine atmospheric structure	WS
Harvard University	L. Goldberg	Center-to-limb variation across the solar disk	WS
University of Iowa	D. A. Gurnett	VLF noise phenomena of ions in plasma around rocket	WI, & FC
SCAS	W. J. Heikkila	Auroral zone disturbances and PCA events	FC
GSFC	J. P. Heppner	Auroral electrojet currents	FC
University of Alaska	K. B. Mather	Electrojet currents and their relation to aurora	FC
GSFC	D. S. Evans	UV stellar spectra	WS
GSFC	E. Boldt	Spectrum of celestial x-ray sources	WS
Lockheed	P. C. Fisher	Low-energy x-ray background	WS
MIT	H. Bradt	Location and energy spectra of x-ray sources near galactic center	WS

PLANNED SOUNDING-ROCKET LAUNCHINGS
BY NASA IN 1967
(continued)

<u>INSTITUTION</u>	<u>INVESTIGATOR</u>	<u>EXPERIMENT</u>	<u>LAUNCH SITE</u>
Columbia Radiation Laboratory	R. Novick	Search celestial sphere for weak x-ray sources	WS
Lockheed	L. W. Acton	Intensity of solar x-rays	WS
Harvard University	R. Huguenin	Cosmic noise background with instruments designed for Pilgrim	WI
GSFC	W. N. Ness	Electron beam created to simulate aurora	WI
GSFC	J. R. Herman	Composition, electron density and collision frequency in the ionosphere	WI
GSFC	D. S. Evans	Energy and density of electrons in the aurora	FC
GSFC	W. S. Muney	Obtain solar spectral data to calibrate OSO spectrometer	WS
Johns Hopkins University	W. C. Fastie	Auroral spectra in the far uv	FC
Western State College of Colorado	T. Violette	Solar spectral emission near Lyman- α , - β line	WS
Ames	W. H. Hansen	Test flight of Solar Pointing Aerobee Rocket Control System (SPARCS)	WS
GCA	J. Pressman	Airglow and chemical release	FC
University of Michigan	F. Haddock	Cosmic background spectrum	FC & WI
Rice University	R. C. Haymes	Ionospheric current system	WI
Catholic University	C. S. Bowyer	Search for celestial x-ray sources	Brazil
Naval Ordnance Test Station	A. J. Kruejer	Solar uv irradiance and comparison with OGO measurements	WS
University of Minnesota	J. R. Winckler	Trapped radiation belts	WI

TABLE 3
PLANNED SOUNDING-ROCKET LAUNCHINGS
BY AFCRL IN 1967

<u>INVESTIGATOR</u>	<u>EXPERIMENT</u>	<u>LAUNCH SITE</u>
R. S. Narcisi M. Smiddy	Ion density	Eglin
M. Smiddy	Ion trap	Eglin
N. W. Rosenberg	Atomic oxygen variation	Eglin
N. W. Rosenberg	Ozone determination	Eglin
D. P. Hoult	Instrumentation test	Eglin
J. Sandock	Auroral absorption	FC
N. W. Rosenberg	Barium diffusion rates	Eglin, WI
H. E. Hinteregger	Extreme uv monochromator	WS
S. Silverman	Auroral physics	Brazil, FC
R. C. Sagalyn	Spherical electrostatic analyser	Puerto Rico
J. McIsaac	Density (bremsstrahlung)	Eglin
J. F. Morrissey	Density (drag technique)	Eglin
N. Sissenwine	Atmospheric turbulence	Eglin
J. Ulwick	Auroral input-output	FC
A. S. Jursa	Atmospheric absorption	WS
D. Golomb	Ionospheric winds	FC, TBD
D. Golomb	Atomic oxygen variation	FC, TBD
R. G. Walker	IR horizon	FC
R. O. Hutchinson	Magnetics	FC
R. S. Narcisi	Mass spectrometry	Eglin, FC, Thule, WS
A. C. Faire	Density (falling sphere and light scatter)	Eglin
R. Vancour	Magnetic fields	FC
N. W. Rosenberg	Ionospheric winds	Eglin, Equatorial site, TBD

PLANNED SOUNDING-ROCKET LAUNCHINGS
BY AFCRL IN 1967
(continued)

<u>INVESTIGATOR</u>	<u>EXPERIMENT</u>	<u>LAUNCH SITE</u>
R. C. Sagalyn	Electric fields and structures	FC
J. Ulwick	Pulse phase delay	Thule
R. Skrivaneck	Micrometeorite flux	Brazil, FC, WS
J. Ulwick	Dual pulse probe	FC, Thule
J. Ulwick	Gyroresonance probe	FC
J. Ulwick	D-region electron depletion	FC
N. W. Rosenberg	CO ₂ in F-region	TBD
A. S. Jursa	UV radiation	WS
N. W. Rosenberg	Dawn-dusk wind variation	Eglin
R. Toolin	Atmospheric optics	Eglin
D. F. Smart	Cosmic radiation	FC
D. Colomb	Ozone luminosity	TBD

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Launching Sites

Eglin - Eglin Air Force Base, Florida 30°25'N, 87°10'W	WI - Wallops Island, Virginia 37°50'N, 75°29'W
FC - Fort Churchill, Canada 58°44'N, 75°29'W	WS - White Sands Missile Range, N.M. 32°24'N, 106°32'W
PB - Point Barrow, Alaska 71°21'N, 156°47'W	TBD - To be determined

APPENDIX III

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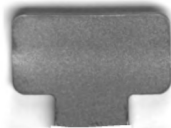
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